Intel’s Quality System
1998

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THE CHAIRMAN'S VIEW OF QUALITY

Intel is engaged in a quality revolution. Quality has always been our most important value. Over the last few years, we've dedicated ourselves more than ever before to embedding into our workforce two key concepts: customer satisfaction and continuous improvement.

The purpose of this publication is to serve as a reference for the quality and reliability of Intel's products, services, technologies and management systems.

To date, our devotion to customer satisfaction and continuous improvement has garnered us the honor of being rated number one, number two or excellent in quality by over 93% of our major customers. This quality Vendor of Choice rating is critical to our success. We won't be satisfied until it's 100%.

It takes an exhaustive effort to achieve world-class quality, but we know of no other way to succeed. Semiconductor technology continues to increase in complexity at a pace faster than ever before. Respectively, the Pentium? ?and Pentium Pro microprocessors have 2.5 and 4.2 times as many transistors as the Intel48?? ? microprocessor and approximately four times as many as the Intel38?? ? microprocessor? a sixteenfold increase in five short years. Enabling production technologies provide 0.35-micron capabilities (traces roughly 1/300th the diameter of a human hair), with future capabilities providing consistent 0.25-micron resolution.

As our products become more powerful and incorporate more system functions and capabilities, quality and reliability are more important than ever. In many applications, component failure simply cannot be tolerated.

Why our products almost never fail is part of the story we have to tell in this publication. The first chapter gives an overview of our quality philosophy, systems and standards. Successive chapters provide more specific and technical details. This structure, together with a detailed table of contents, should help you find the information you need.

Intel is committed to being your Vendor of Choice. Through a process of continuous improvement, we expect to meet your ever-increasing demands for quality products and services.

Gordon E. Moore
Chairman Emeritus

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Intel's Quality Culture

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CHAPTER 1
INTEL'S QUALITY CULTURE

INTRODUCTION

At Intel, total quality is our number one objective. We believe that it is achievable only through customer satisfaction and continuous improvement of all aspects of our business. In fact, customer orientation and commitment to aggressive improvement are at the heart of our corporate values.

We recognize that total quality reaches far beyond the performance of outgoing products and services. That's why we pursue innovation and improvement in all of our business processes, systems and methods. In addition, rather than simply detect and correct defects in the later stages of production, we strive to build quality and reliability into every step of our design, development and manufacturing processes.

Our commitment to total quality is supported by the ongoing development of our people. We continually seek better ways of delivering the education, training and tools our employees need to meet evolving challenges. We recognize that increases in personal effectiveness have a measurable impact on the quality of our output, from a highly complex microprocessor to a monthly report.

Employees across the corporation focus on doing what is necessary to meet and often exceed customer expectations. The commitment to external customers also extends to internal customers, as we emphasize the importance of providing quality work to our co-workers. By maintaining this dual focus on external and internal customers, we direct every action, task and expectation toward increasing customer satisfaction. As an example of our productive partnerships with external customers, we integrated their expectations into the design of our Pentium and Pentium Pro microprocessors to meet their growing demands for application-intensive processors.

The quest for total quality delivers a wealth of advantages to Intel and customers alike. High-quality, timely products and services not only help our customers succeed, but also reduce our cost of doing business and steadily increase our market share. We're extremely proud that customers worldwide continue to rate Intel product quality number one, number two or excellent. This selection as our customers' quality Vendor of Choice (VOC) and Preferred Quality Supplier (PQS) is testimony to our ongoing efforts to provide the highest possible levels of quality.

In this chapter, we provide an overview of quality at Intel, including our total quality evolution, culture, quality system and quality organization.

INTEL'S TOTAL QUALITY EVOLUTION

In our early years of doing business, we focused primarily on developing new technologies and meeting quantity demands. Today, the emphasis on quality is paramount. Not only do our customers insist on high-quality products and services, but quality has become a major factor in achieving business objectives in a global market. For example, 1% to 5% defect rates were standard in the semiconductor industry over a decade ago. Within the last decade, defect rates have declined so significantly that they can be measured in terms of defects per million (DPM).

Thanks to a rigorous process of feedback, control and steady improvement in both process and product, Intel now consistently offers a defect rate of less than 100 DPM. This is a dramatic improvement over our 20,000 DPM (2%) level in the late 1970s and a sign of our customer orientation and commitment to quality. As we prepare for the century ahead, we've set extremely aggressive goals, demanding ever-decreasing defects in the products that we manufacture.

In the 1970s, we placed major emphasis on manufacturing yields and product reliability. Along with increasing our yields and lowering our DPM levels, we improved our failure in time (FIT) rates and set increasingly stringent reliability goals (see Figure 1-1).

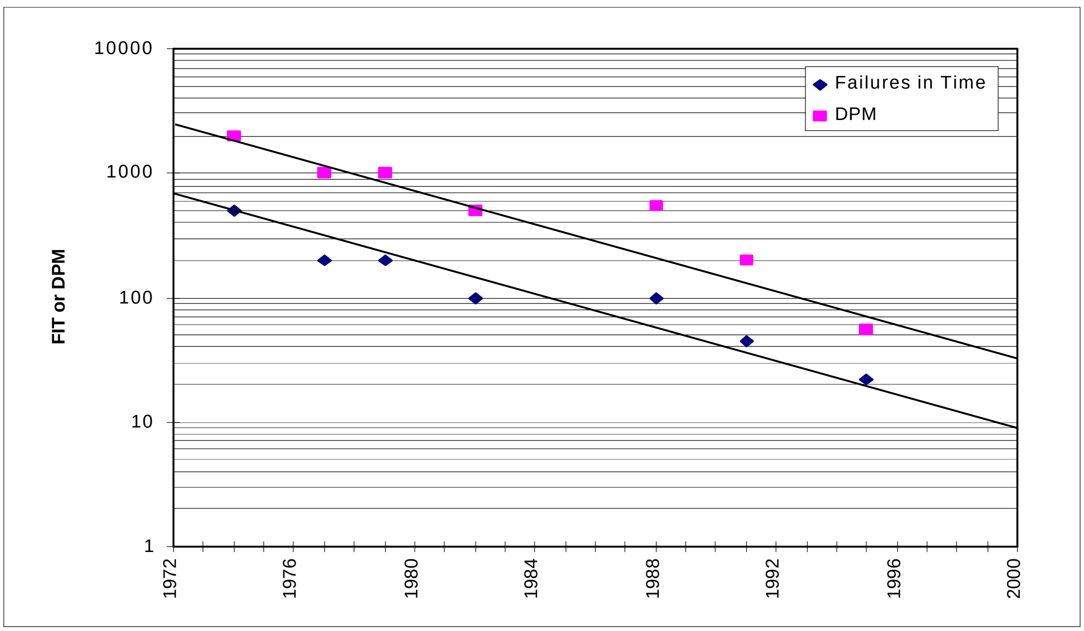

Figure 1-1. Trends in Reliability Goals.

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In the ’80s, our focus expanded to include an emphasis on manufacturing leadership and process quality. Figure 1-2 highlights some of the major quality initiatives and tools that we’ve implemented since the early 1980s. To drive improvements, we introduced statistical methods, design of experiments, statistical process control, a systematic problem-solving process called Quality Improvement Process (QIP) and other tactics. During this period, we played a dominant role in identifying and solving reliability problems, and dedicated substantial resources to meeting and exceeding our own escalating standards for integrated circuit reliability. As today, keen attention was paid to quality and reliability criteria in all phases of a product’s life cycle.

Intel was responsible for numerous reliability breakthroughs in the 1980s, including the discovery of alpha particle-induced soft errors and the causes of package electrostatic discharge. We pioneered the use of the emission microscope, which has been instrumental in discovering the sources of latch-up, understanding electrostatic discharge and studying circuitry. Additionally, we led the way in dynamic fault imaging, which is used to trace error sources in integrated circuits.

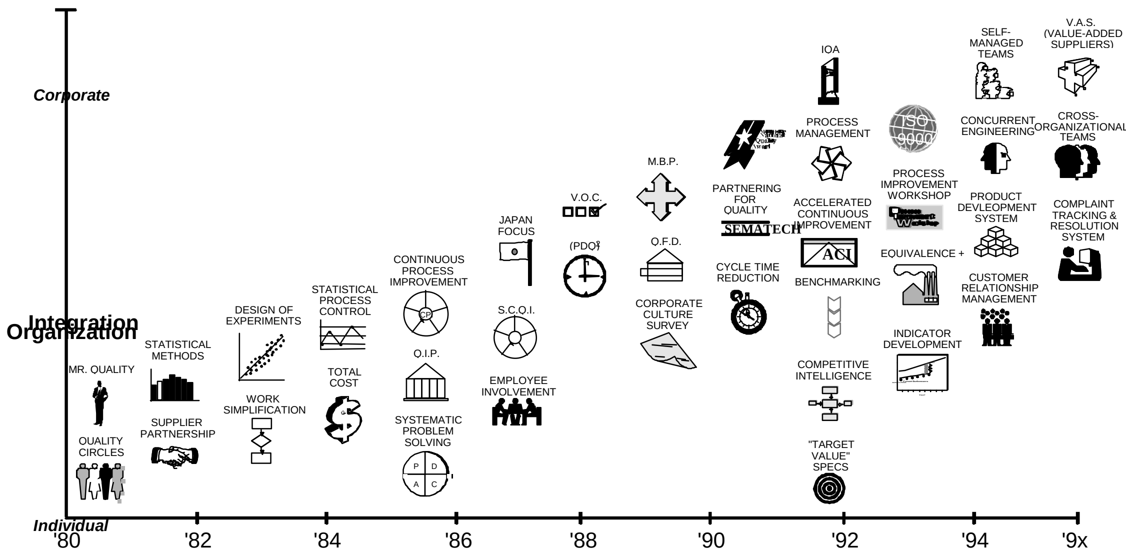

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Figure 1-2. Total Quality Implementation Roadmap

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Our commitment to improving on-time delivery performance, measured as Intel Commit Date (ICD), also evolved significantly in the 1980s. In 1985, we considered our delivery on time if product was shipped 14 days ahead of or seven days after the committed shipping date. In 1987, when customers indicated that a 21-day window was unacceptable, we tightened the window to seven days ahead and four days late. Late in 1987, we began measuring on-time deliveries against specific customer-defined expectations, and again tightened the average delivery window to seven days ahead and zero days late. By the end of 1989, the average window had narrowed to five days ahead and zero days late. In the 1990s, the ICD delivery window average is approaching three days ahead and zero days late. In the 21st century, we project the customer's needs for product shipment to be even tighter.

Our aggressive pursuit of improvement continues in the 1990s. Today, we're focused on total quality leadership, encompassing not only technological and manufacturing quality, but "people quality" as well. For example, we recognize the importance of the ISO 9000 standards and have actively participated in ISO registration activities since 1991. ISO 9000 elements make up Intel's baseline quality system and are used as a template for designing factory quality assurance systems. Now we're meeting and, in many cases, surpassing the guidelines established by the ISO 9000 standards. All of our mature component and boards/systems manufacturing sites have been registered to date, along with various support organizations. ISO 9000 registration efforts, combined with our rigorous performance improvement programs and robust process control processes, have increased customer satisfaction around the world, in terms of both products and services.

The productivity levels of Intel people also continue to rise in the '90s. We've experienced healthy increases in recent years in productivity per employee (see Figure 1-3) and revenue per employee. Thanks to such increases, we're able to improve cost performance, ultimately benefiting our customers.

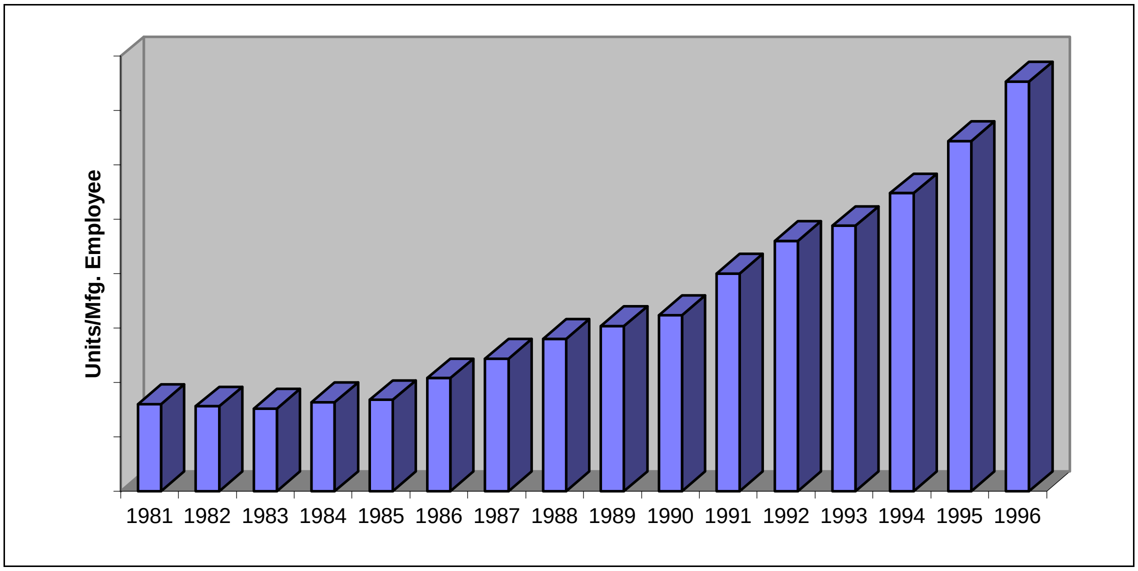

Figure 1-3. Intel Productivity Improvement

INTEL'S TOTAL QUALITY CULTURE

Intel's corporate values and the behaviors that support them provide employees with more effective ways to work and create a culture in which total quality is strongly supported. Our values of customer orientation, discipline, quality, risk taking, great place to work and results orientation define Intel's commitment to excellence in both the marketplace and the workplace (see Figure 1-4).

In practicing our values and the behaviors that support them, we seek to:
?
??Continuously improve the customer-perceived value of our products, processes and people **(work bette**r).
??Continuously reduce the time it takes to perform every activity **(work faste**r).
??Continuously reduce our total cost of doing business **(work cheape**r).

By working better, faster and cheaper, we strive to increase customer satisfaction with our performance solutions, product quality, support, delivery and availability, cost and pricing, and responsiveness.

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INTEL'S QUALITY CULTURE

Customer Orientation

? Listen and respond to our customers, suppliers and stakeholders.
? Clearly communicate mutual intentions and expectations.
? Deliver innovative and competitive products and services.
? Make it easy to work with us.
? Be vendor of choice.

Discipline

? Conduct business with uncompromising integrity and professionalism.
? Ensure a safe, clean and injury-free workplace.
? Make and meet commitments.
? Properly plan, fund and staff projects.
? Pay attention to detail.

Quality

? Achieve the highest standards of excellence.
? Do the right things right.
? Continuously learn, develop and improve.
? Take pride in our work.

Risk Taking

? Foster innovation and creative thinking.
? Embrace change and challenge the status quo.
? Listen to all ideas and viewpoints.
? Learn from our successes and mistakes.
? Encourage and reward informed risk taking.

Great Place to Work

? Be open and direct.
? Promote a challenging work environment that develops our workforce.
? Work as a team with respect and trust for each other.
? Manage performance fairly and firmly.
? Be an asset to our communities worldwide.

Results Orientation

? Set challenging and competitive goals.
? Focus on output.
? Assume responsibility.
? Constructively confront and solve problems.
? Execute flawlessly.

Figure 1-4. Intel Values and Supporting Behaviors

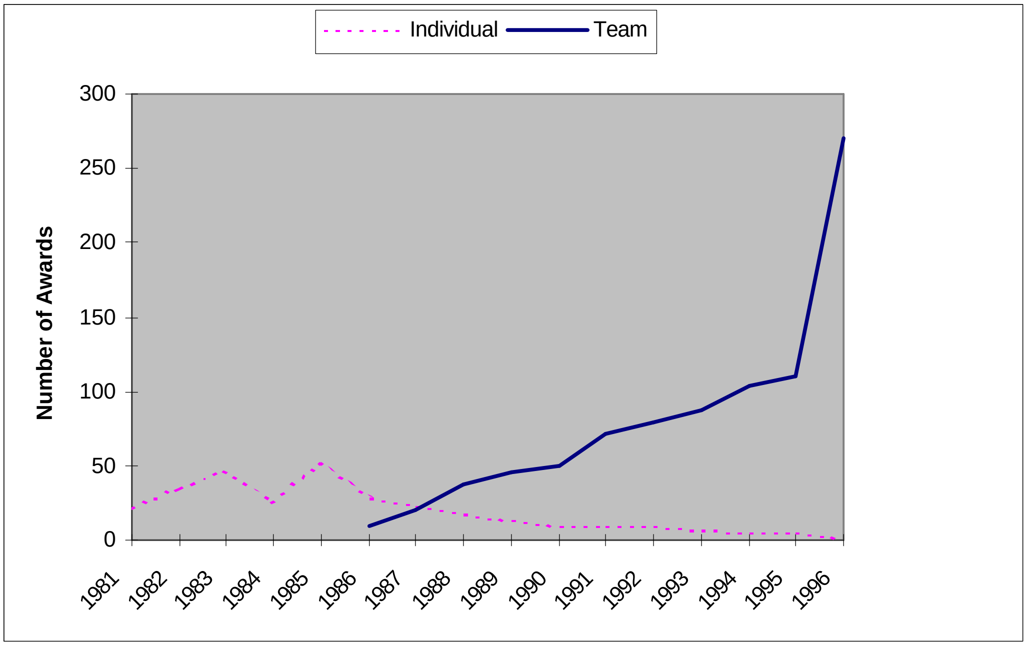

Figure 1-5. Intel Achievement Awards

Recognition programs are also key to fostering Intel's total quality culture. We formally recognize the achievements of individuals and teams in a variety of ways. The Intel Achievement Award (IAA) honors individuals and small teams for specific outstanding achievements that have a major impact on the company's operations. The Intel Quality Award (IQA) highlights organizations that make extraordinary contributions while exemplifying the corporate values.

Because the solution of problems often requires the resources and creativity of more than one individual, we frequently build teams that are cross-functional, cross-organizational or multilevel in composition. Accordingly, many of our recognition awards honor outstanding team achievement. For example, the coveted Intel Achievement Award, once called the Individual Achievement Award, was renamed to address the unique contribution made by teams. Figure 1-5 shows the trend toward team recognition at the corporate level.

Winners of the Intel Quality Award have made a conscientious, long-term commitment to boosting their overall performance and to increasing Intel's competitiveness. The IQA's self-assessment process enables organizations to define their strengths and areas for improvement in light of the corporate values. This process is a powerful tool for improving our focus on continuous improvement and achieving a higher level of excellence. The IQA challenges groups to set goals for performance and improvement, and then to aggressively pursue these ideas over time. Moreover, as part of the IQA process, winners share their ideas and methods with groups across the corporation. We believe that there is a direct connection between

steady improvement in performance to our values and our ability to achieve Intel's mission. By improving performance to our values, we continue to find new and better ways to do a great job for our customers, employees and stockholders.

Intel's total quality environment also emphasizes effective management. Managers are expected to make quality their first priority and customer satisfaction a top concern. In addition, they're encouraged to manage on the basis of fact, focus on continuous process improvement and build trust. The results of this management philosophy are direct and measurable. For example, a focus on process quality has led to numerous achievements, including a 73% percent cut in average component design time—from more than 80 weeks in 1986, to 40 weeks in 1989, and 23 weeks in 1995 (see Figure 1-6). Correspondingly, we have also dramatically reduced process introduction time.

Finally, a sincere respect for our people and ongoing investment in them are key to effective management. As we've evolved toward a total quality environment, our emphasis on providing the right training and education at the right time and cost has steadily intensified. In 1996, we spent nearly 7% of our annual payroll for training, more than 2.3 times the national average.

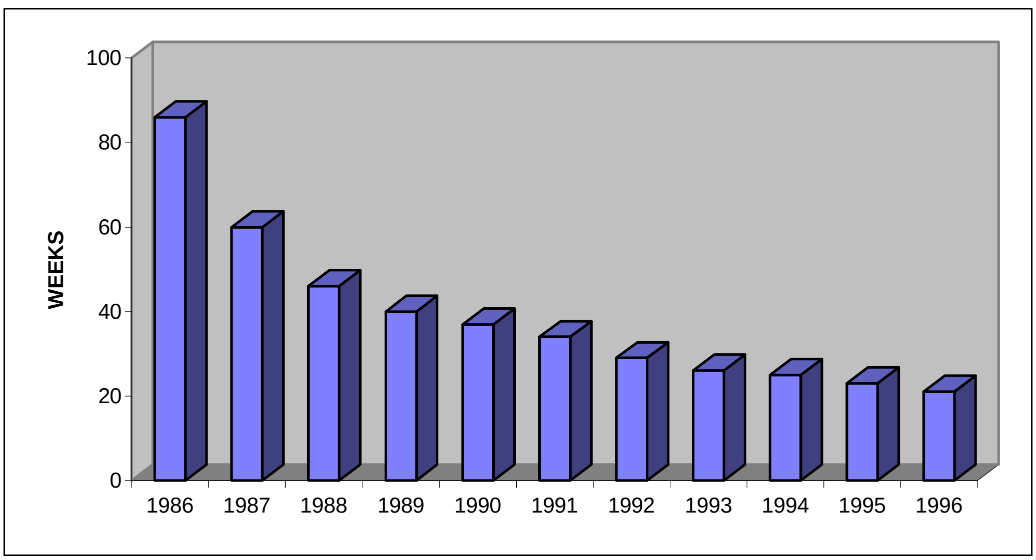

Figure 1-6. Average Weeks from Definition to Sample Component Design Time

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INTEL’S QUALITY SYSTEM

Introduction

As shown in Figure 1-7, our Quality System architecture comprises two basic elements: a Quality Leadership System and a Quality Operating System (QOS). The first drives our management processes. The second provides a framework for ensuring predictable, consistent product quality and quality service support. In the discussions that follow, we’ll review the key features of both systems, beginning with our Quality Leadership System.

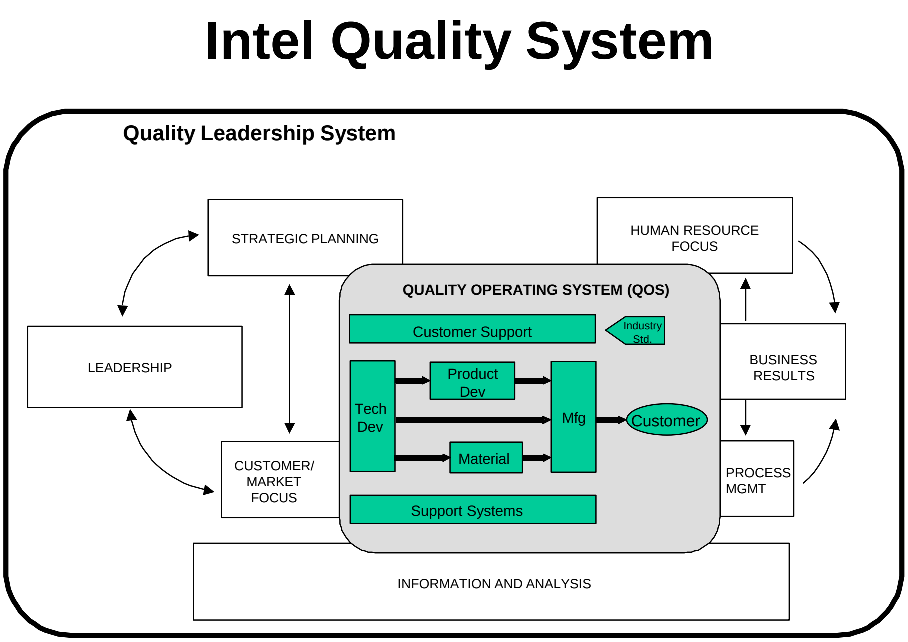

Figure 1-7. Intel’s Quality System

Intel’s Quality Leadership System

INTRODUCTION

Our Quality Leadership System focuses on quality management practices and is strategically mapped to the Malcolm Baldrige National Quality Award Criteria for Performance Excellence. This system encompasses a wide range of knowledge and tools. The following sections briefly describe our approach to each of the Baldrige total quality categories, as well as some of the tools used to achieve excellence.

LEADERSHIP

Intel’s current leadership system has been evolving since the corporation was founded in 1968. Promotion from within, long a strong point for the company, provides us with top leaders who are very knowledgeable about the company’s products and technology.

Our integrated planning system provides some of the framework that we use to set, review and evaluate our direction (see the following section). Corporate strategic objectives, owned by our top executives, form the cornerstone of the direction-setting process within our planning system. Typically, three to five strategic objectives receive focus and are evaluated, modified as appropriate and communicated to Intel employees worldwide. Channels for communicating the objectives include our extensive intranet backbone, posters, identification badge attachments and Business Update Meetings (BUMs). BUMs are hosted quarterly at every major site within the company by our most senior managers and executives to ensure that every Intel employee knows and understands our business. Among other issues, BUMs address corporate objectives, company values, past and future financial results and expectations, the business and competitive environment, and customer focus imperatives.

A third means for instilling our corporate values, innovation and continuous improvement is the annual Intel Quality Award (IQA) process, described earlier in this chapter. The IQA recognizes Intel organizations for outstanding performance to the corporate values. Key to the IQA process is the final review by senior executives, who must comprise over 60% of the Executive Review Team in accordance with award guidelines.

STRATEGIC PLANNING

Strategic planning requires the integration of a strategic quality planning system into typical business planning activities. Planning for quality improvement is a normal part of short- and long-term planning efforts. Moreover, quality considerations have the same priority as or a higher priority than other business planning objectives.

A series of courses called “Managing at Intel” provides managers with a Planning at Intel (PAI) module. The PAI process, which encompasses long-range, annual and individual planning, aligns resources necessary to achieve Intel’s business objectives down to the project level. PAI has been taught to senior executives at Intel, who then deploy it throughout their organizations.

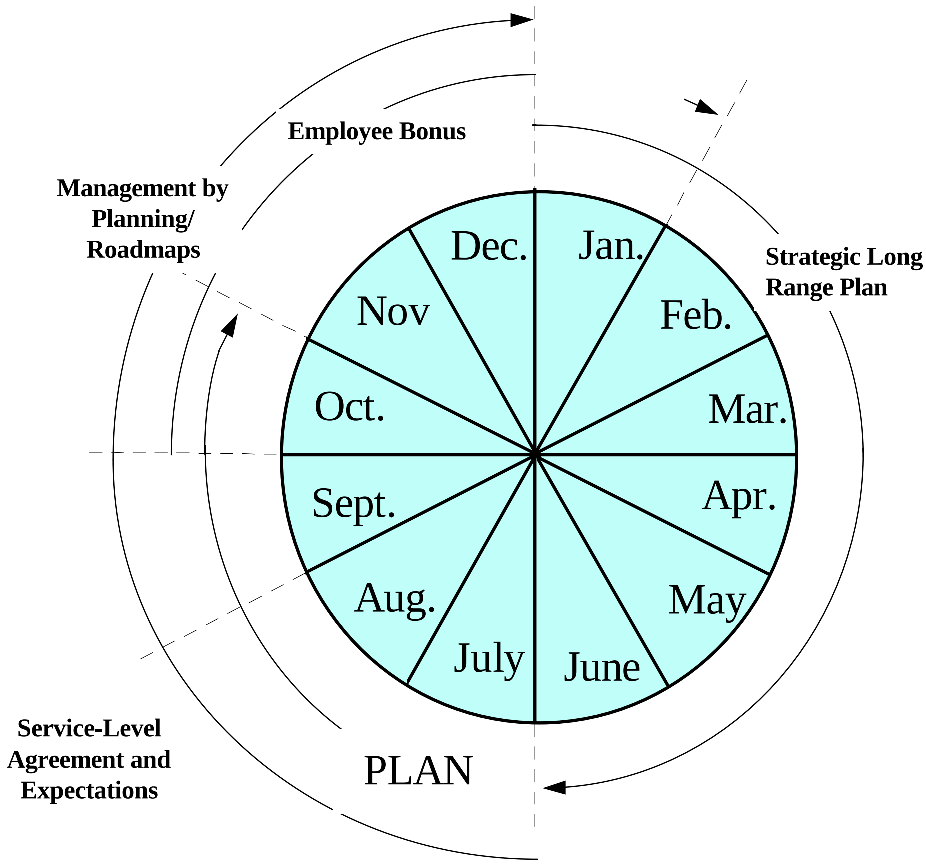

Figure 1-8. Strategic Planning Cycle

Generally, the PAI process begins with a current situation analysis, which identifies areas needing strategic focus. This involves a variety of tools and activities, such as customer satisfaction surveys and benchmarks against competitors. Assessments of our future direction, our industry, the world economy, political trends and other factors also are used. With this information, we're prepared to develop or revise our strategic long-range plan (SLRP). Encompassing a three- to five-year outlook, SLRP serves as the basis for Intel's annual plan. Figure 1-8 illustrates the strategic planning cycle.

The annual plan identifies strategies for meeting corporate objectives, the people responsible for implementing those strategies and the necessary tactics. Tactics are then transformed into projects and programs. Taking ownership of these projects and programs, employees create quarterly delivery plans.

Through this planning sequence—current situation analysis, strategic long-range planning, annual planning and quarterly delivery plan?¾the PAI process ensures that individual employee planning impacts our corporate business objectives. Because plans are nested vertically in the organization and resources are aligned cross-functionally, we can optimize the interfaces between organizations and better meet these objectives.

Under the PAI process, projects are funded according to zero-based-budgeting principles. Specifically, projects are prioritized and the available resources (in terms of dollars and people) are allocated only to the most important. This funding method, combined with specific planning processes, allows PAI to align the resources necessary to achieve Intel's business objectives down to the project level.

CUSTOMER/MARKET FOCUS

Customer satisfaction is not only the result of Intel's total quality implementation but also its driver. On a quarterly basis, we collect information directly from customers to better understand their issues and concerns. Using a tactical assessment, we ask customers to rate approximately 22 attributes in terms of their importance and satisfaction. Where there are differences, or "gaps," between these two perspectives, Intel's functional and business groups analyze the causes and align resources as needed to meet prioritized customer concerns (see Figure 1-9). We then close the loop back to the customer with data, improvement plans or both.

Ultimately, Intel measures customer satisfaction in two ways: (1) We apply customer feedback to arrive at a composite score for our overall performance, i.e., excellent, good, fair or poor; and (2) we use a relative measure of better than, equal to or worse than the competition. A subset of our Vendor of Choice program, known as the Preferred Quality Supplier (PQS) program, specifically measures customer satisfaction with Intel quality. While tabulated in the same way as VOC, PQS focuses on three key areas: (1) specific quality issues, such as segmented product performance; (2) the performance of specific quality systems, such as change management, functional analysis/correlation requests and return material authorization; and (3) certain nonproduct quality attributes, such as administrative quality. Quality managers associated with each business function respond to quality gaps and their causes with specific action plans for process improvement. This process of regularly seeking customer feedback enables us to listen to our customers on a continual basis and feed information back into our quality operating systems so we can continue meeting and exceeding their requirements.

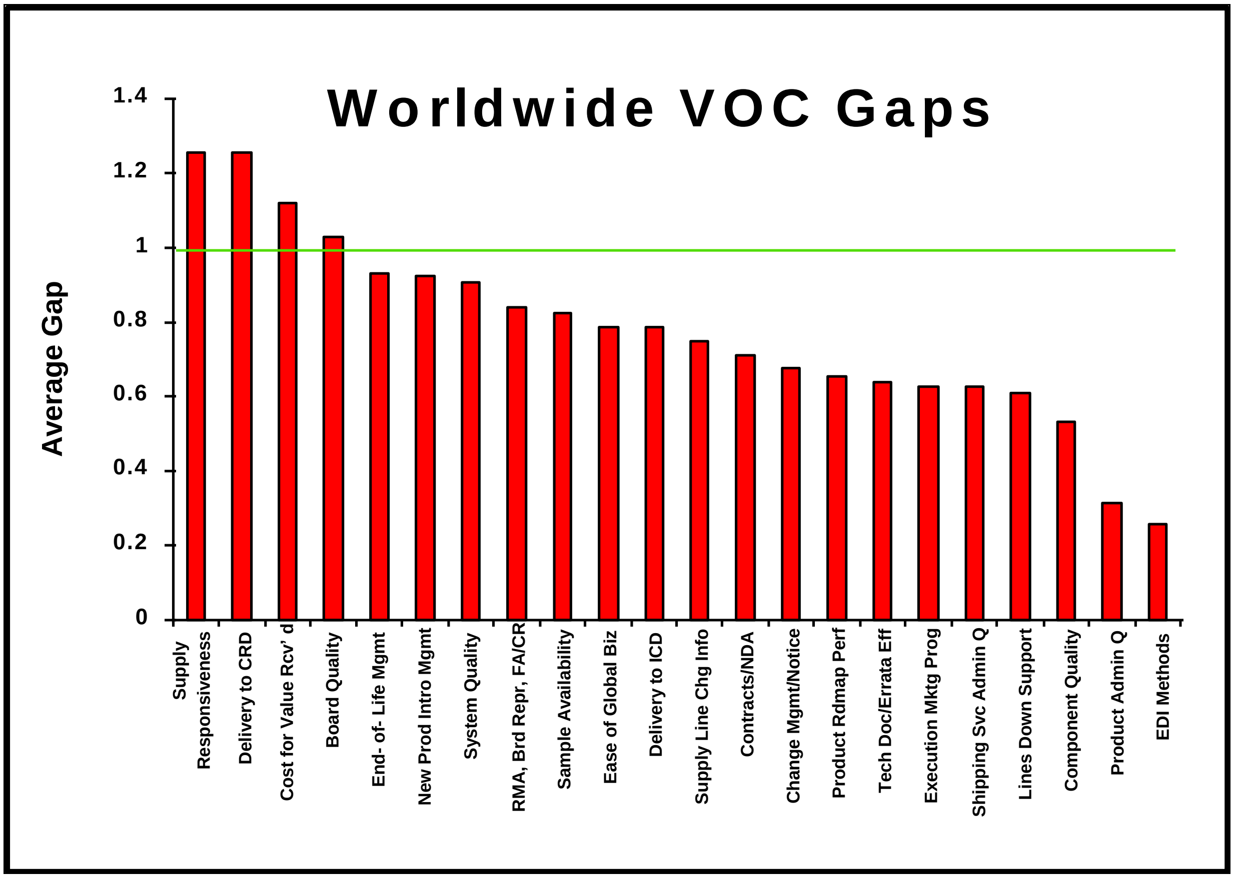

Figure 1-9. VOC Customer Gaps

INFORMATION AND ANALYSIS

The next component of our quality roadmap is a comprehensive quality management data system. We collect volumes of quality data throughout our operations so we can track quality problems, conduct root cause analysis and fix problems as quickly and permanently as possible. All data is evaluated regularly for timeliness, reliability and accessibility.

We use a seven-step method to solve and document quality problems, as shown in Figure 1-10. A standardized format allows process improvement teams to benefit from one another’s work. As shown in Table 1-1, the common tools used throughout Intel for continuous improvement are cross-referenced to each step in the seven-step problem-solving methodology. These tools represent just a small fraction of the techniques in the general classification. More advanced statistical process control and management tools are used across Intel on both product and service improvement activities.

INTEL'S QUALITY CULTURE

Other tools in the information and analysis area include check sheets, Pareto chart analysis, fishbone diagrams, histograms, trend charts and Gantt charts. Among the more advanced tools used are design of experiment, basic statistics and graphs, process capabilities, critical path analysis, PERT charts, matrix diagrams and force field analysis.

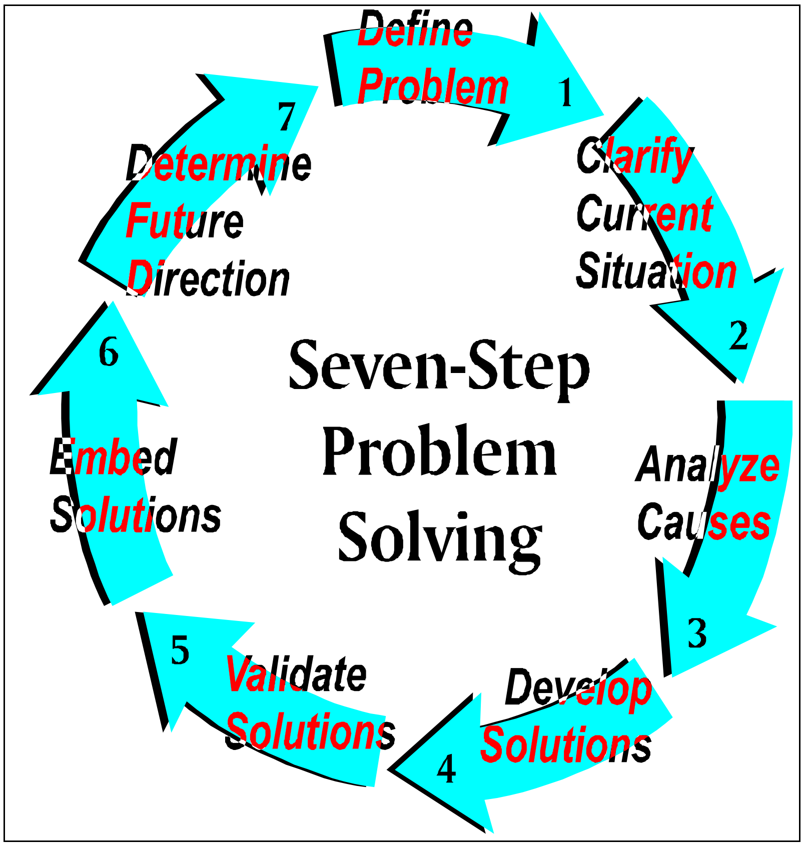

Figure 1-10. Seven-Step Method

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Table 1-1. Continuous Improvement Approach and Steps

Continuous Improvement Approach	Steps in Structured Problem Solving						
	Define Problem	Clarify Current Situation	Analyze Causes	Develop Solutions	Validate Solutions	Embed Solutions	Determine Future Direction
Success Tree Analysis				✓		✓	
Business Process Re-engineering				✓			✓
Cause-and-Effect Diagram			✓				✓
Brainstorming			✓	✓			✓
Analysis Hierarchical Process			✓				
Benchmarking			✓	✓			✓
Scatter Plots			✓				
Process Flow Diagram		✓	✓			✓	
Check Sheet		✓	✓		✓		
Five Whys/Two How's	✓	✓	✓				✓
Self-Assessment Methodology-Lite	✓	✓	✓				✓
Pareto Charts	✓	✓	✓		✓		✓
Principles of Variation	✓	✓	✓		✓	✓	✓
Histogram	✓	✓	✓		✓		✓
Trend Analysis	✓	✓	✓		✓		✓
Strengths, Weaknesses, Opportunities, Threats (SWOT)		✓	✓	✓		✓	✓
Root Cause Analysis	✓	✓	✓	✓			
Indicator Development	✓	✓	✓	✓	✓	✓	✓

HUMAN RESOURCE FOCUS

Intel’s process for integrating new employees into the corporation begins immediately after hire. Every new employee, regardless of work experience, requires an orientation to Intel and some period of time to fully integrate with the new job and work environment. The integration period is the critical time to reinforce Intel’s values and culture, particularly as they relate to the employee’s organization. During their first six to nine months with the company, all new employees must take three integration courses that are designed to help them succeed in their positions and thus ultimately satisfy their customers.

First-day training concentrates on the necessary paperwork, an introduction to Intel and our values, and what to expect in the coming months. Second in line is the Working at Intel (WAI) course. This full-day class helps the employee:

- Clarify a written list of deliverables for the first few months.
- Map the Intel values to the skills learned.
- Identify actions to build and maintain respect and trust in a diverse environment.
- Identify essential elements for teams to be successful.
- Apply effective problem-solving techniques to a real issue.
- Apply appropriate decision-making methods to a real issue.
- Demonstrate effective meeting techniques.
- Plan and conduct a one-on-one meeting in which a problem is confronted constructively.
- Identify tools for dealing with a rapidly changing environment.
- Develop an action plan for accomplishment of individual deliverables.

Third in the series is the ESM (Executive) Forum. In this session, a senior executive of the corporation asks questions and facilitates discussion. New employees are encouraged to raise issues, ask the executive questions and discuss how to succeed as a new hire at Intel. We believe this series to be crucial to initial new employee development.

We also make a deliberate, ongoing investment to upgrade the skills and knowledge of all employees, managers and non-managers alike. Training is delivered through Intel University, our internal training structure, and a variety of other programs. Intel University plays a significant role in the annual, personal development plans of most employees by providing training on topics such as interpersonal skills, information management and design methodologies. To improve team effectiveness, training is also offered in such areas as team development, brainstorming and team leadership. At a more advanced level, employees can learn facilitation and negotiating skills, among others. Basic training on customer focus is also provided, emphasizing the importance of customer support and satisfaction. Central to this training is the understanding that each person’s work or output has an impact on the customer.

Additionally, Intel encourages and offers financial assistance for job-relevant employee education or training at outside institutions. Here the focus is on acquiring skill sets that have been defined by the businesses as critical to meeting current or emerging challenges. While specifics in the hard or soft quality sciences are included, these programs also address the larger needs of the business.

PROCESS MANAGEMENT

Management for predictability requires a thorough knowledge of processes, a working control system and an integrated methodology for continuous improvement. Our Quality Operating System (QOS), which is described briefly over the next few pages, provides these critical functions for all products, manufacturing processes and product-related services at Intel. In addition, we work with our suppliers to set challenging quality goals for their processes, products and services; evaluate their progress at regular intervals; and provide feedback to help them meet their quality targets.

All other support and service areas are addressed in a way that is most appropriate to their needs and objectives. Employee training is rigorously tracked, evaluated and improved to ensure competency in all areas of each position. Internal business partnerships are monitored, evaluated and improved through the use of our Partner of Choice (POC) scorecard and process. The Human Resources group, for example, uses both the POC as well as a Point of Service (POS) survey to ensure that products and services meet the corporation’s continually evolving needs. In these ways, all areas of the corporation are continually managed, evaluated and improved to do a great job for our customers, employees and shareholders.

BUSINESS RESULTS

At Intel, we regularly track, trend (as appropriate) and evaluate results from all of our key operations, processes, products, services, customers and suppliers. All areas have set timelines that are appropriate to the specific processes being measured. Key outputs from these analyses are published regularly to those with a need to know as a report or presentation, or via an intranet web site. We use this data to support our day-to-day management, direct our planning or leadership systems, and drive or evaluate improvement efforts. We believe that strong business results in all areas are our ultimate measure of success.

Intel’s Quality Operating System

As product complexity and performance steadily increase, Intel must meet a wide range of new challenges to maintain world-class quality and reliability. To anticipate these challenges and achieve consistently superior results, we employ a Quality Operating System that spans all of our product lines. The QOS enables us to:

?? **Communicate one uniform quality system for all of our products from silicon to systems.** This allows Intel organizations, external customers and suppliers to clearly understand our corporate wide quality and reliability efforts.

Intel's Quality Operating System

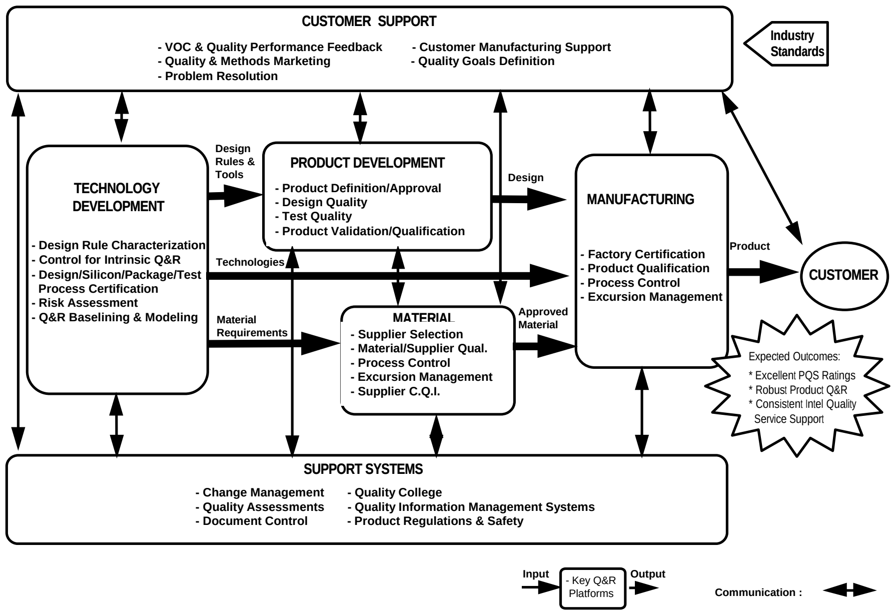

Figure 1-11. Quality Operating System Detail

?? **Build quality into our products, processes and systems.** This enables rapid growth with robust product quality and reliability. It also ensures consistent, progressive quality service support.

?? **Create a common framework and language for sharing and documenting best-known methods.** This significantly accelerates individual and group learning.

As shown in the detailed view in Figure 1-11, our QOS focuses on functions instead of organizations. The arrows depict a high-level view of the inputs/outputs and communication/interface paths between the functions. As Figure 1-11 illustrates, our QOS architecture has six core functions:

?? Customer support
?? Technology development
?? Product development
?? Manufacturing
?? Material
?? Support systems

Each of these core functions comprises four to six key quality and reliability-based platforms. A key Q&R platform is a number of linked activities that are used in producing a product or service for a customer/user within or outside Intel, and that are considered vital to the success of a core function. For example, a key Q&R platform for the core function of customer support is problem resolution. In another example, a key Q&R platform for the core function of support systems is change management.

For each key Q&R platform, we've defined associated outcomes, methods, tools, and quality measures and goals. This detailed information helps us identify and make improvements in our platforms across operations, and thus drive consistency and systematic improvement throughout Intel. It enables diverse groups to clearly communicate with one another about their quality efforts and to share proven methods. By applying information on proven tools and methods, we also can bring up new operations rapidly while maintaining excellent quality levels. In addition, we can train new people quickly and effectively by acquainting them with the specific tools, methods and procedures used within their organization. The remaining chapters of this publication describe many of the key quality methods and tools employed corporate wide.

To drive continuous improvement of our QOS, we've developed a special assessment process that measures the success of our quality deployment. This assessment, which is conducted on a regular basis, integrates results from a wide range of assessment and audit processes already in place throughout Intel. Intel's Quality Operating System is a dynamic system that will steadily evolve in response to changing business requirements and customer expectations. By making ongoing, aggressive improvements to our QOS, we will continue to achieve superior quality results and strive to attain the highest possible levels of customer satisfaction.

INTEL'S QUALITY ORGANIZATION

Introduction

The quality function at Intel is implemented at a corporate, or cultural, level and at a product level. The Quality Technology arm of Intel's Business Practices Network addresses the first, while our Corporate Quality Network focuses on the second.

Intel's Business Practices Network

Reporting to the Vice President and Director of Human Resources, the Business Practices Network (BPN) is chartered with helping Intel management evolve and embed a business improvement environment. This environment provides the means to improve our business performance as reflected in our corporate mission and values.

BPN works hand in hand with Intel operations to develop and deploy corporate wide systems where appropriate. A major objective of BPN is to standardize quality improvement processes throughout the corporation, making them consistent globally. Jointly with key members of Intel's various business and manufacturing groups, BPN is responsible for developing business improvement-related processes, methods, techniques and training courses. It is also chartered with coaching senior management on business improvement processes. Key to this coaching is the deployment of Intel's Baldrige-based self-assessment process, which is the foundation of the Intel Quality Award process discussed earlier.

Intel's Corporate Quality Network

Intel's Corporate Quality Network (CQN) is a vital part of our total quality environment. CQN's mission is to deliver, with its Intel partners, world-class, market-competitive product quality and reliability while driving breakthrough practices for the business.

To accomplish this mission, CQN is aligned with all major business and functional groups at the senior staff level. This alignment offers a twofold benefit: (1) It provides management with a one-stop source for all issues related to quality and reliability; and (2) it ensures that quality and reliability considerations are factored into all aspects of technology, design, manufacturing, material and business practices.

CONCLUSION

If there is one constant in the volatile marketplace of the '90s, it is change itself. Technologies, products and markets are evolving at such a rapid pace that to remain competitive, companies must not only meet current customer needs, but anticipate continually emerging requirements.

To satisfy customers' changing needs for quality and reliability in products and services, Intel has a flexible Quality System architecture that can adapt quickly and effectively to new business trends. This architecture, encompassing a wide range of mature and robust systems and processes, enables us to provide responsive support to customers and optimize their use of Intel products.

Our total quality culture at Intel, which is based on a commitment to customer satisfaction and continuous improvement, drives us to set ever-higher standards and expectations for our quality and reliability systems. Our ultimate goal is to help today's, and tomorrow's, customers succeed in an increasingly competitive market.

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Customer Quality Support

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CHAPTER 2
CUSTOMER QUALITY SUPPORT

INTRODUCTION

Intel's pursuit of total quality leadership in products and services is driven by a central, uncompromising objective: to make Intel and our customers successful in a fast-changing marketplace. The ultimate goal of our quality support efforts is to increase our customers' competitiveness and reduce their cost of doing business with us. We strive to respect the values and views of our customers, understand and respond to their needs, and communicate mutual intentions and expectations.

The escalating pace of business in the '90s also demands that we continually increase the speed with which we deliver support to our customers. We believe that our commitment to evolving ever-faster, more responsive support solutions is crucial to helping customers use Intel products successfully and to decreasing their time-to-market.

In this chapter, we provide an overview of the network, systems and services that deliver customer quality support for all of Intel's product lines.

CUSTOMER QUALITY SUPPORT NETWORK

Introduction

To serve customers' escalating market demands, Intel uses a multi-channeled quality support network that is implemented in all of our locations worldwide: North America, Japan, Asia-Pacific and Europe. Intel's Customer Quality Support Network provides our direct and distribution channel customers with rapid problem identification, problem resolution, technical support and information services.

Sales and Marketing

Intel Sales and Marketing is normally the customer's first point of contact for customers who buy products directly from Intel. Field sales engineering (FSE), located around the world, is the primary customer interface managing present and future customer needs. Field sales engineers service the customer's daily business requirements, future design activities and post-sales support needs. Field application engineering (FAE) provides field systems engineering service for all phases of customer development and support. Field application engineers provide a broad spectrum of support, including assistance in using new products,

application development, personalized training, and technical and management consultation. Customers who buy Intel products from a distributor should contact that distributor for technical support and information services.

Customer Quality and Reliability Engineering

To maintain customer service excellence throughout a varied customer base and product line, Intel has a Customer Quality and Reliability Engineering (CQ&R) group. This group provides customers with easy access to Intel for responsive support on product quality matters. CQ&R is responsible for:

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- ?? Understanding customers' quality and reliability requirements and expectations.
- ?? Resolving customer usability and quality issues.
- ?? Recommending standard and uniform quality goals based on customer expectations.
- ?? Driving quality program implementation.
- ?? Delivering Manufacturing Advantage Service (MAS) collaterals.

Customer quality engineers (CQEs) are the Intel interface on most quality and reliability issues. CQEs transfer Intel quality and reliability information generated by design, development, manufacturing and support systems to the customer and, conversely, receive and disseminate customer information to Intel. CQEs periodically hold formal reviews in which customers provide their assessment of the quality and reliability of Intel's products and services. They manage quality systems information, quality programs, product qualification information, quality and reliability data, customer audits and other customer support issues.

Product quality engineers (PQEs) are responsible for analyzing product failure, doing device correlation, resolving test correlation issues, providing engineering analysis expertise and resolving other component quality issues of a technical nature. These product-specific technical engineers ensure technical product support mainly through the functional analysis/correlation request (FA/CR) system (see Problem Response section).

Quality Support Centers

CQ&R has seven major Quality Support Centers (QSCs) worldwide, with four in North America and one each in Europe, Japan and Asia-Pacific. The North American Quality Support Centers are aligned with specific Intel product groups located in Santa Clara and Folsom, California; Portland, Oregon; and Chandler, Arizona. Figure 2-1 illustrates Intel's geographic Quality Support Center model..

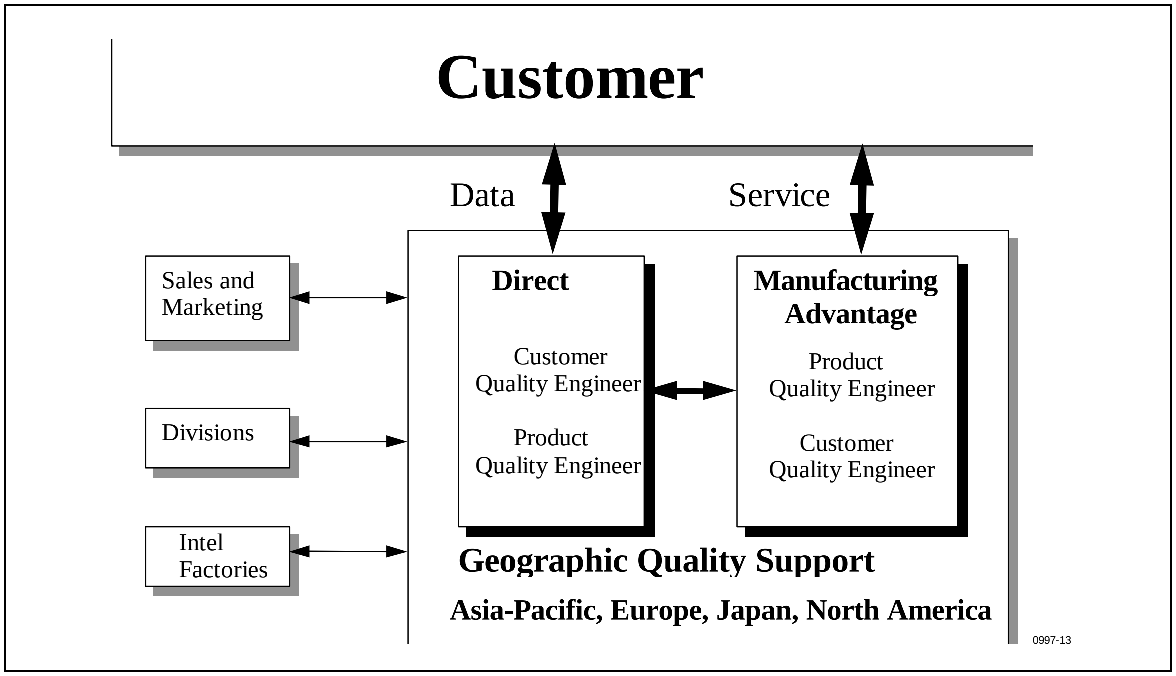

Figure 2-1. Intel's Geographic Quality Support Center Model

All Intel Quality Support Centers focus on problem resolution through:

- ?? Customer lines-down resolution.
- ?? Intel product quality or reliability improvement.
- ?? Customer manufacturing process improvements.
- ?? Customer board design improvements.
- ?? Risk assessments that drive customer action.
- ?? Customer manufacturing yield improvement (defects per million reduction).
- ?? Product usability support.

Repair Centers

In addition to the Quality Support Centers, Intel has four major Repair Centers worldwide, with one each in North America, Europe, Japan and Asia-Pacific. These Repair Centers provide competitive hardware service for Intel motherboards and systems under warranty. The United States Repair Center (USRC) is located in Chandler, Arizona. In-warranty repair services include:

?? Field warranty repair for boards and platforms.
?? Engineering change order upgrades.
?? Warranty confirmation.

The throughput time for in-warranty board and platform repairs is 15 days. The Repair Centers are staffed by board and system repair specialists, and can provide automatic test screening using Intel's standard factory tests.

CUSTOMER QUALITY SUPPORT SYSTEMS AND SERVICES

Introduction

Intel provides several quality support systems and services to facilitate customer success. These systems are designed to help Intel understand customer needs and to furnish customers with valuable information about Intel products and services. The following sections describe some of these systems so that you can use them to their maximum benefit. Effective use of these systems, along with clear communication and teamwork between appropriate personnel at Intel and your company, can lower your cost of doing business, reduce your time-to-market and increase your competitiveness. Contact your local Intel representative or the Intel Customer Support Hotline (1-800-628-8686) to find out how you can get started with any of the available services.

Problem Response

Direct customers, those who buy product directly from Intel, have the option of contacting their local Intel representative or the Customer Support Hotline to resolve any technical issues arising from the use of Intel products. Our functional analysis/correlation request (FA/CR) system handles technical issues relating to the use of Intel components. This system addresses three areas:

?? Failure analysis of devices that are perceived as failing to meet agreed-upon customer expectations for quality and reliability.
?? Correlations for customers who experience incoming inspection failures or device qualification or application problems.
?? Analysis of manufacturing-line fallout as part of specific product defect reduction programs.

Intel's failure analysis policy is to use electrical failure signature analysis along with comparison to the product database to validate random failures and ensure low total failure rates. Complete physical failure analysis is performed only on reliability excursions and new repeating electrical signatures. The complexity of failure analysis is rapidly growing as (1)

processes become steadily more complex, with multiple layers of metal pitch, and higher transistor count and density; and (2) product complexity increases.

Due to the high cost of failure analysis, it must be combined with data analysis, technology models and Pareto methods. This allows Intel to focus resources on improvement versus isolation of random defects.

The Intel Customer Support Hotline also handles boards and systems technical issues for direct customers. The hotline handles the initial customer discovery, which determines customer impact, gathers background information and looks at how the customer is experiencing the problem. The current issue is compared with a database of known problems to determine if there are known resolutions and what steps must be taken next. If the hotline is unable to resolve the problem at the time of the call, the issue is documented in a database, prioritized with the customer and tracked until it is resolved. Resolution of an issue does not necessarily imply a fix, but could mean its documentation as an erratum with appropriate workaround solutions.

Distribution customers, those who buy Intel product from distributors, should contact their distributor for support of any technical issues arising from the use of our products.

Manufacturing Advantage Service

Intel's Quality Support Centers offer a Manufacturing Advantage Service program (see Figure 2-2) to provide practical manufacturing solutions for our new technologies. The goal of this program is to help our customers achieve the fastest time-to-market and -money, while ramping to high-volume production. Manufacturing Advantage makes it easier for customers to use Intel products in their manufacturing environment by providing technical information, practical assistance, training and product support. This accelerates our customers' manufacturing learning curve, enabling them to achieve high yields with superior quality and reliability. For more information, search Intel's website at **http://www.intel.com** under **Manufacturing Tip**s.

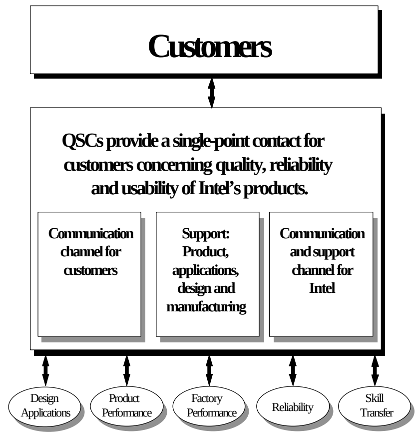

Figure 2-2. Intel's Manufacturing Advantage Service Model

Application Support

The Intel Customer Support Hotline also delivers support via a team of engineers dedicated to providing general and technical information. This group is separated into focus teams that provide customers with in-depth knowledge and support on individual products, such as microprocessors and flash products, and on quality and reliability topics.

The Quality and Reliability team supports the entire Intel product line, providing assistance to customer quality engineers and product engineers who are designing in Intel parts. Intel Application Support can be reached from 5:00 a.m. to 5:00 p.m. Pacific Standard Time at 1-800-628-8686.

Customer Information

The increasing complexities of today's technology and the growing expectations of the marketplace have created the necessity for a quality and reliability customer information program at Intel. As part of our continuous quality improvement strategy, we review our methodologies to identify new possibilities for improvement of our systems. It is our intention to provide customers with continuous quality improvement information about components, boards, systems and processes.

By visiting Intel's home page on the World Wide Web at **http://www.intel.co**m, customers can download a variety of quality and reliability information. Examples of this information include:
?

- ?? Technical product specifications and updates.
- ?? Intel technology journals.
- ?? Literature Center with:
  - ? ?Product application notes.
  - ? ?Datasheets.
  - ? ?Manuals.
  - ? ?Architecture overview.
- ?? Development tools for products and technologies.
- ?? Manufacturing tips.
- ?? BIOS upgrades.

Components Change Notification

In a dynamic marketplace, change is a given. Intel's leading-edge products and culture of continuous improvement demand a robust change management process. Product changes may result from the need for additional manufacturing capacity, cost reductions or quality improvements. Communicating changes to customers and ensuring their readiness to receive changed product are key elements of Intel's change management system.

Our goal is to provide world-class product change notification services to our customers in order to meet market and business demands. Our objectives are to:
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- ?? Ensure that critical information is communicated, including expected customer impact.
- ?? Provide sufficient customer evaluation time.
- ?? Eliminate non-value-added notification.
- ?? Provide rapid feedback to customers.
- ?? Enable factory ramps, product enhancements and process improvements for customers and Intel that are fast and controlled.

Intel's notification criteria are centered around the result of the change. For example, if the proposed change affects the form/fit/function of the end product in a customer's application, notification will be provided. Form/fit/function encompasses:
?

- ?? Changes to external dimensions or appearance (materials, package, or shipping materials) that are key to a customer's fitness for use (e.g., manufacturing flow and incoming quality checks).

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- ?? Changes to product characteristics (electrical or physical) that are key to functionality in a customer's manufacturing process or application.

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Notification classifications address three types of changes:
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- ?? **Approval.** Major changes that affect the form/fit/function of the end product. These changes may exceed current product data sheet parameters, or may be within product data sheet parameters but have significant known impact on the customer's application (e.g., electrical/performance characteristics) or customer's manufacturing process.

- ?? **For Your Information (FYI).** Changes that have a minor effect on the form/fit/function of a product. These changes will not exceed current product data sheet parameters but may have some impact on a customer's manufacturing process. These types of changes are not expected to require samples or validation activity by the customer. Examples include label changes, packing material changes and mark or ordering code changes.

- ?? **No Notify.** Changes that do not affect the form/fit/function of a product. An example is the movement of manufacturing from one equivalent facility to another.
  Notification timings for approval-type changes are:

- ?? **Product Change Notification (PCN):** 90 days.

- ?? **Samples:** 60 days.

- ?? **Qualification Data:** 14 days.

Notification timings for non-approval type changes are:

- ?? **FYI:** 30 days.

- ?? **No Notify:** zero days (no need to notify the customer of this type of change).

Various types of communication media are used for notifying direct customers of a change. The two primary types of media used are a Monthly Conversion Summary (MCS) and the Product Change Notice (PCN). The MCS is a forecast providing the customer with a roadmap of future changes, while the PCN is the actual notification of the change. Conversions listed in the MCS are planned, and customers are encouraged to initiate sample ordering in order to proactively assess any impact to their applications. We strive to communicate the PCN electronically in order to aid our customers' internal processes. Once the customer has received the PCN, it is time to take action. Table 2-1 lists the attributes of each communication medium.

Because conversions are a fact of life in our dynamic industry, speed and execution are important criteria for success. We expect early, proactive communication on potential issues from customers in order to meet or beat their expectations.

Table 2-1. Attributes of Media for Customer Notification

Media Attributes	MCS	PCN
Conversion Number	X	X
Conversion Title	X	X
Type of Change	X	X
Type of Notification		X
Customer Approval Deadline		X
Recommended Action for Customer		X
Description	X	X
Milestones	X	X
Products Affected	X	X
Order Codes Affected	X	X
Reference Documents		X
Actions Required		X

Boards and Systems Change Notification

Change is also a given in the boards and systems business, and often occurs more rapidly than in the components business. Changes may result from the need for additional manufacturing capacity, vendor changes, cost reductions or quality improvements. Communicating these changes to our direct customers in a timely manner is key.

Intel's notification criteria are centered around the result of the change. For example, if the proposed change affects the form/fit/function of the end product in a customer's application, notification will be provided. Form/fit/function encompasses:

?? Changes to external dimensions or appearance (e.g., edge connectors or board dimensions) that are key to a customer's fitness for use (e.g., manufacturing flow and incoming quality checks).

?? Changes to board/system characteristics (electrical or physical) that are key to functionality in a customer's manufacturing process or application.

Notification timings range from a minimum of five to 60 days depending on the complexity, urgency and impact of the change. The majority of changes are of an FYI type and do not affect form/fit/function. However, they do have an impact on the Bill of Materials (BOM) used and therefore could affect the customer's manufacturing process. An example of a no-notify change is the movement of manufacturing from one equivalent facility to another. The Monthly Conversion Summary, also described in the previous section, is the common standard used to communicate current and future changes regarding boards and systems.

Your local Intel representative provides the MCS. Table 2-2 shows MCS attributes as they apply to boards and systems customer notification.

Customer Audits and Quality Survey Questionnaires

INTRODUCTION

It is our intention to assist customers in assessing the effectiveness of Intel's quality system. In the past, our primary assessment vehicle was the on-site compliance audit. As our factories have become ISO registered, and as our internal audit program has become increasingly robust, we've made data from these activities available to customers. As a result, we've nearly eliminated the need for customers to perform formal/routine audits of our manufacturing facilities. Figure 2-3 illustrates our success with this approach in our component manufacturing facilities.

Table 2-2. MCS Attributes for Boards/Systems Customer Notification

Media Attributes	MCS
Conversion Number	X
Conversion Title	X
Type of Change	X
Recommended Action for Customer	X
Description	X
Milestones	X
Products Affected	X
Order Codes Affected	X

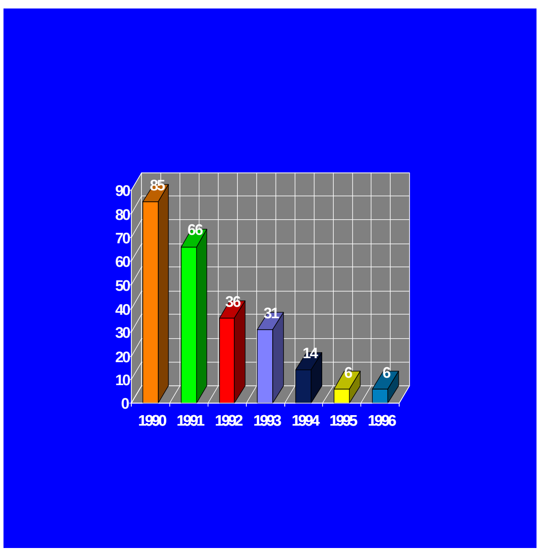

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Figure 2-3. Customer Audit Activity

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Customer Quality Survey Questionnaires

In most cases, it is more effective to complete a quality survey questionnaire than to perform a routine on-site audit. Quality survey questionnaires that need to be completed by Intel should be sent to your Intel representative with a requested completion date. The questionnaire is then forwarded to the Corporate Quality Assessment organization, which fills in the applicable information and returns the completed questionnaire to you by the requested date.

CUSTOMER AUDIT SCHEDULING

Occasionally, an on-site audit of an Intel manufacturing facility is appropriate. In this case, we have a structured process in place to ensure the best outcome for both Intel and our customers. The overall customer audit scheduling flow is illustrated in Figure 2-4.
Intel schedules customer audits as follows:

?? **Audit request.** The customer contacts the local Intel field sales office or the Intel customer quality engineer (CQE) eight weeks in advance with an audit date. The date must be set far enough ahead to allow time for scheduling of key Intel personnel for the audit, and to avoid conflict with other customer or internal audit activities previously scheduled.

?? **Discovery agreement.** The Intel field sales engineer (FSE) or CQE and customer complete the Customer Audit Discovery Agreement. This agreement ensures that the site or operation understands the needs of Intel's customers and provides the most efficient audit agenda.

?? **Review of audit request.** The Corporate Quality Assessment organization reviews each customer audit request with the appropriate Intel parties to determine if an audit is the most effective way to meet the customer's needs.

?? **CNDA and CITR.** The site or organization to be audited verifies that a Corporate Nondisclosure Agreement (CNDA) is on file with Intel Contract Management, and a Confidential Information Transmittal Record (CITR) is signed by the auditor(s) before the audit begins.

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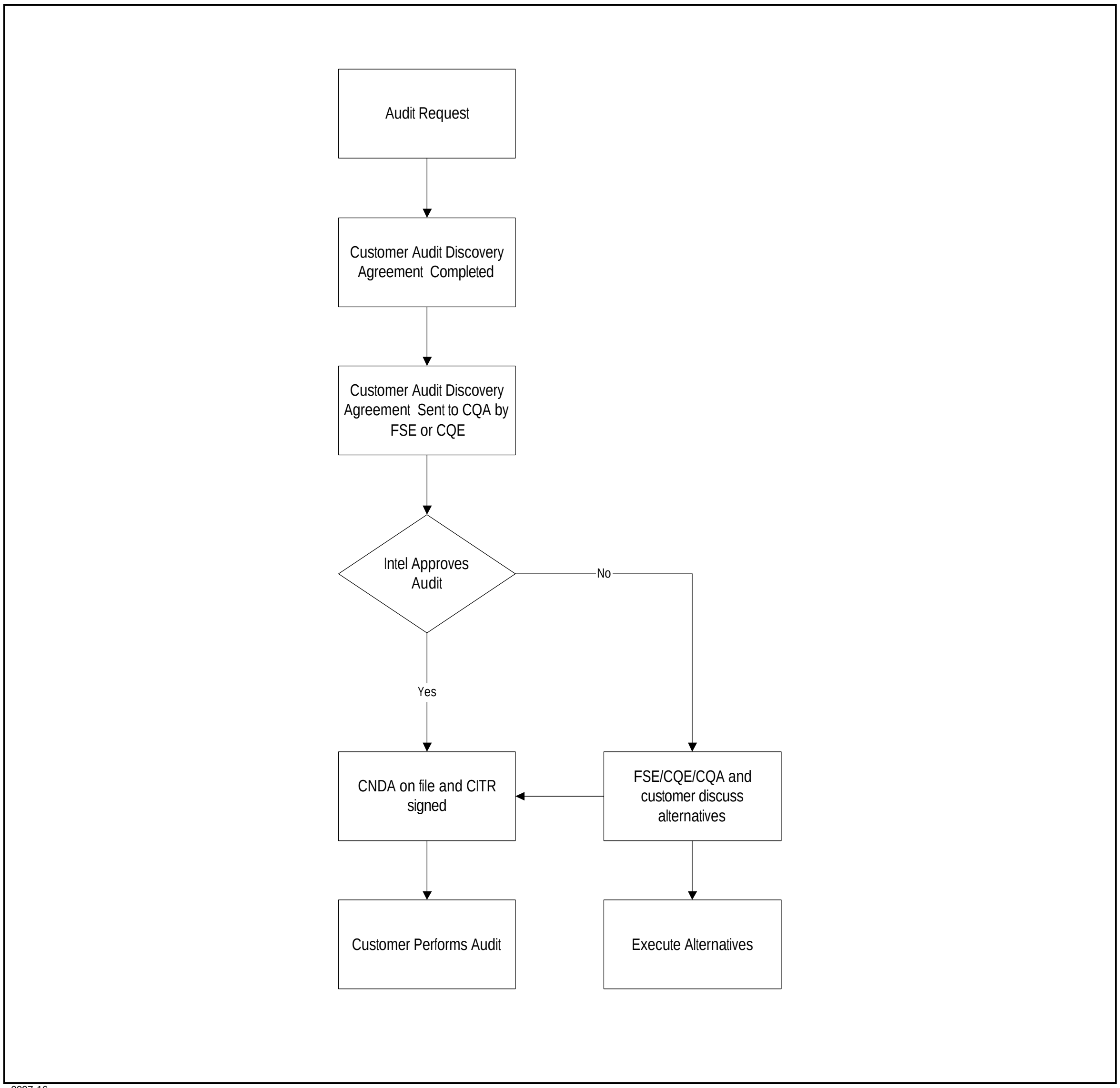

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Figure 2-4. Customer Audit Scheduling Flow

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Customer Specification Review System

Since customer systems may require products and/or services that differ from Intel's standard products or services, we have a Customer Specification Review System to provide customers with a timely comparative analysis of their specification against Intel's standards. The system consists of two main processes: spec reviews (SRs) and general reviews (GRs). SRs occur when customers submit a component specification and request a response with respect to Intel's ability to provide the product per their spec requirements. GRs occur when customers submit their corporate or site general semiconductor specification (GSS) and request a response regarding Intel's ability to meet the requirements, and/or identification of alternatives when needed. Once approved, customer specifications are translated into an Intel special specification (S-spec) and implemented worldwide, as appropriate, via our on-line S-spec/ basic product spec system. Figure 2-5 shows the customer specification review system flow.

Product Literature

A toll-free literature number provides 48-hour turnaround for documentation and literature on Intel products, including data sheets, application notes, customer training information and other documents. To place an order or join Intel's literature update service, simply follow the instructions on the inside front cover of this handbook. Technical information is also available via our World Wide Web address at **http:/www.intel.co**m

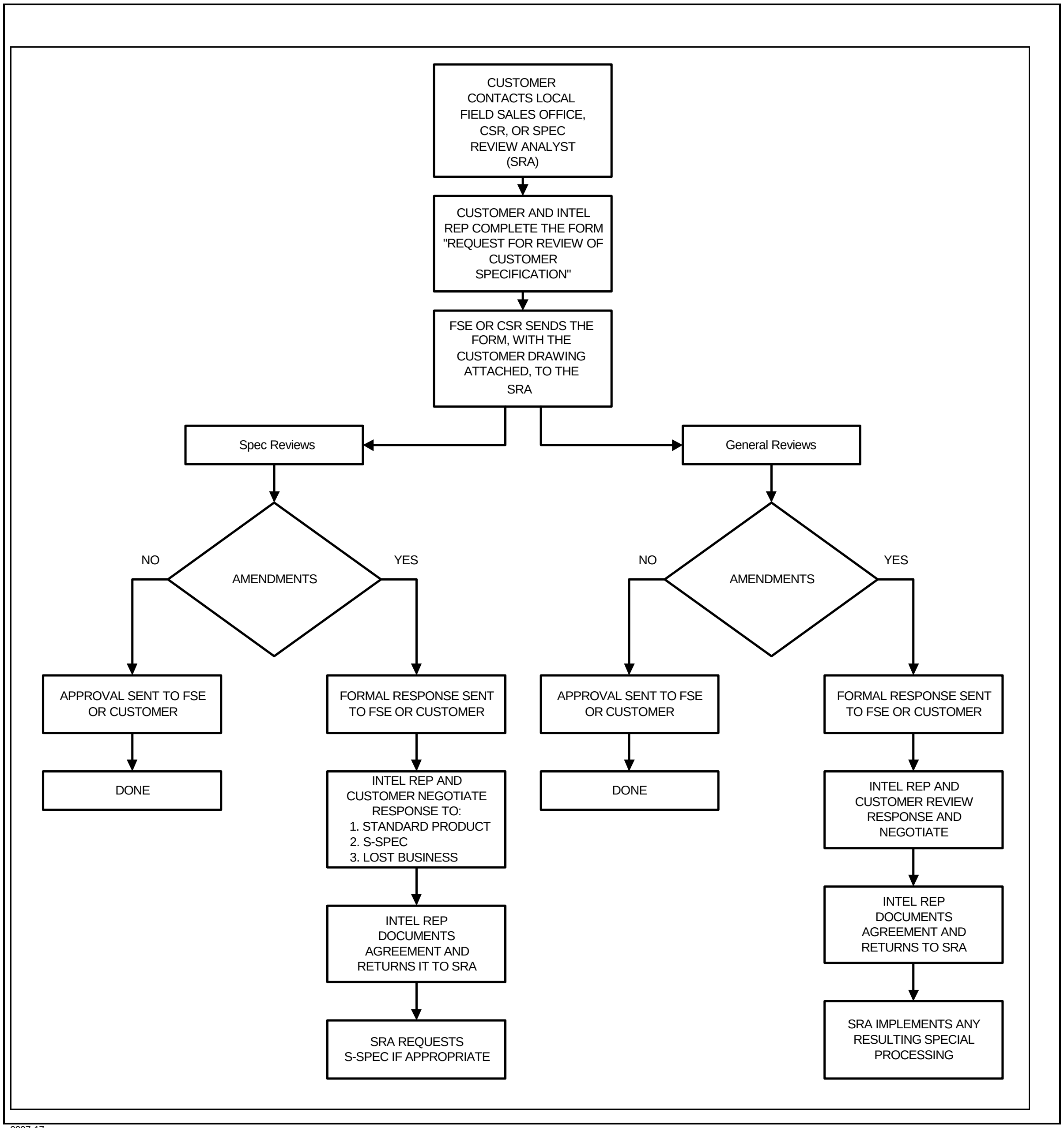

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Figure 2-5. Customer Specification Review System Flow

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CONCLUSION

Intel's customer quality support effectively utilizes information from quality design and development systems, manufacturing systems and support systems to provide high-quality products and services to our direct and distribution customers worldwide. Field customer support, customer quality support and customer support services work together to provide a complete support system for our customers. Local Intel sales and applications engineers, as well as a worldwide network of distributors, are available to support a broad range of customer business requirements. Our Customer Quality and Reliability group manages a wide variety of quality programs and is one of the primary contacts for answering customer questions about Intel's quality system.

To remain our customers' preferred quality supplier in a fast-paced marketplace, we will continue to develop new services that help customers use Intel products successfully and shorten their time-to-market. As an example, we will seek new and better ways to harness electronic communications for responsive customer support, both on the Internet and via video communications using Intel's ProShare™ products. Intel's continuing goal is to provide customers with the highest-quality products, application information and service.

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Design and Development Methodology

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CHAPTER 3
DESIGN AND DEVELOPMENT METHODOLOGY

INTRODUCTION

The rapidly increasing complexity and shrinking feature sizes of each new generation of technology challenge Intel developers to continually evaluate the methodologies they use and to certify new ones that will best support these leading-edge technologies. Assessments to identify areas of potential risk associated with a new Intel technology begin in the earliest stages of design. Risk assessments continue throughout development at all major decision points, with ongoing, rigorous evaluation and certification of tools and processes.

Risk assessments encompass not only the new technology itself, but also all the sub technologies that support it. As shown in Figure 3-1, these sub technologies include the silicon, architecture design, assembly and test technologies needed to design and manufacture next-generation products. Moreover, risk assessments are key in synchronizing all of these sub technologies with respect to product development and introduction.

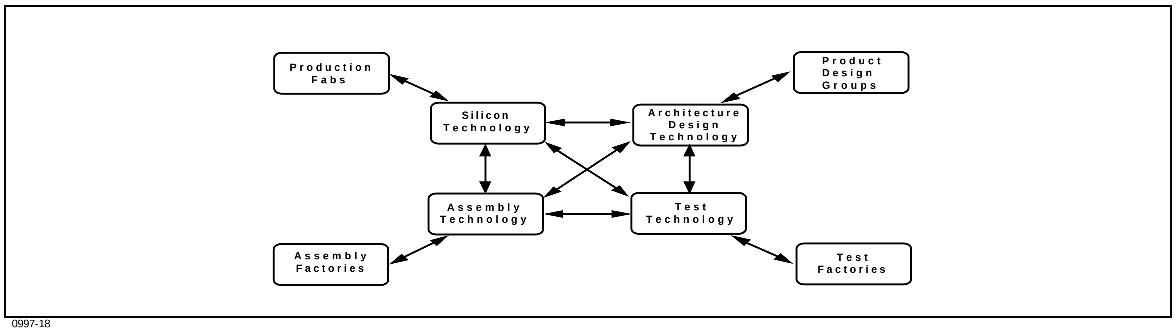

Figure 3-1. Development Network

In certifying a new technology, Intel focuses not only on quality and reliability issues but also on manufacturability and performance. Once a technology has been certified, our Copy Exactly! methodology ensures that it is transferred identically to all Intel users. This approach allows us to ramp new technologies quickly across dispersed locations and enables these organizations to share what they learn for continuous improvement.

In this chapter, we summarize our certification methodology and describe our approach to assembly, process, package and product development. We also provide an overview of our methodology for product qualification.

CERTIFICATION METHODOLOGY

Introduction

Intel certifies silicon, motherboards, modules and assembly manufacturing processes to validate their robustness. A process achieves certification when it has been demonstrated to have a low level of risk for product introduction and ramp. Specifically, the process must:

??Have defect levels and failure rates that meet competitive goals.

??Be free from wear out during a product lifetime.

??Be statistically capable and manufacturable in volume.

??Have been demonstrated to satisfy the above conditions across a process "envelope." For a given process, an envelope is a multidimensional region of characteristics (die size, molding compound, bond pad pitch, etc.) that can impact quality, reliability and/or manufacturability.

??Have a complete set of quality operating systems and monitors.

Intel's certification methodology continues to evolve and improve. We place enormous emphasis on continuous improvement and aggressively seek customer feedback for improvements to our process, package and product development systems.

Manufacturability

In addition to the quality and reliability requirements that are the traditional ingredients of certification plans, manufacturability requirements are an important consideration. Manufacturability requirements cover both design and execution and include a number of indicators: critical-step process control capability, line yield, die yield and in-line monitors.

Including these manufacturability requirements in our certification methodology has resulted in a better integration of our quality and reliability and engineering development teams.

Proactive Engineering

Certifications continue to emphasize proactive engineering early in the development cycle, starting with an upfront risk assessment of potential issues. When problems show up late in the development cycle, product introductions can be delayed, affecting customer commitments and creating crises for the development team. Therefore, Intel strives to anticipate problems before they arise. The more we concentrate on problem detection and resolution in the beginning, the more likely it is that we will have a smooth transition into manufacturing and that customer commitments will be met.

Continuous Information

Rather than gather reliability data on a fixed number of production lots, Intel performs continuous certification throughout the development cycle. Material from the very first fabrication runs passes through the same evaluations as mature runs. The objective is to start gathering information as quickly as possible. Intel’s certification methodology is a result of a desire to make reliability, quality and manufacturability a part of the design effort and ensure performance to goals through continuous assessment.

Certification Methodology System

The overall certification system integrates process, package, motherboard, module and system certifications. System and component qualification is dependent on the reliability of fab and assembly processes. Therefore, Intel qualifies products in tandem with fab and assembly process certifications to ensure that there are no product-sensitive reliability failure modes.

Yield, quality and reliability improve as a new product or assembly process matures. Uncertainty decreases in both a statistical and a general sense. Intel judges the rate of progress using a risk assessment methodology with defined risk levels. A process achieves certification only after all areas are judged to be low risk based upon substantial data and understanding.

There are three major types of certifications. Technology certification is the initial validation of a new manufacturing process. Transfer certification is the validation of a new manufacturing facility, such as a wafer fabrication plant. A manufacturing upgrade certification verifies a change or set of changes introduced into the process to improve yields, process margins or performance.

PROCESS DEVELOPMENT AND CERTIFICATION

Introduction

The development of a new wafer or motherboard fabrication process is the responsibility of Intel's Technology Development organization and its associated Reliability Engineering group. The development activity is driven by a need to improve reliability, boost performance, increase functionality or reduce cost. Since there are a number of ways to achieve these goals, the team must determine the approach that optimizes all variables. Whatever tradeoffs are made, the result must satisfy an internal or external customer need, and the process must be transferable into production.

Before a process can be transferred into production, it must be capable of hitting the target performance goals, be cost-effective and manufacturable, and meet the corporate reliability requirements. What follows is the procedure that the Technology Development and Quality and Reliability groups use to produce a fabrication technology that satisfies both our customers' needs and our internal requirements.

Technology Development Quality and Reliability

The Technology Development Quality and Reliability group is responsible for ensuring that new technologies are reliable, meaning there are no intrinsic wearout mechanisms, the defect densities are enough to allow efficient and economical manufacturing, and the layout and circuit design rules provide sufficient margins to guarantee reliable operation throughout the life of the product.

Most device performance improvements, cost reductions and design functionality increases are possible because of the continually shrinking geometries of new technologies. However, this scaling can be potentially limited by several manufacturability and reliability factors. Lithography constraints such as equipment and photoresist capabilities determine the amount of transistor scaling that can take place (see Table 3-1).

Table 3-1. Impact of Ideal Scaling on Device Dimensions and Materials Parameters

Scaling Factor K>1	Ideal Scaling
Dimension	
Channel Length l_E	1/K
Channel Width Z_E	1/K
Gate Oxide Thickness t_{OX}	1/K
Field Oxide Thickness t_{FOX}	1/K
Junction Depth X_J	1/K
Contact Dimension A	1/K
Line Width W	1/K
Metal Thickness t	1/K
Material Parameters	
Well Doping N_A	K
Field Implant Dose	K^2 or 1, Depending on voltage scaling

Reliability constraints also have a significant impact on the amount of scaling that can take place (see Table 3-2). Reliability is affected by scaling, because scaling gives rise to larger current densities, higher chip temperatures and higher electric fields during device operation.

Table 3-2. Impact of Dimensional Scaling from Table 3-1 on Device Electrical Parameters

The cases for both scaled and unscaled supply voltages are shown.

Shrink Factor K>1 Electrical Parameter	Ideal Scaling	
Supply Voltage	**1/K**	**1**
Device Current *1	1/ÖK–1/K	K–1
CMOS RMS Current/Contact/Line	1/ÖK**	K**
Metal Current Density J_M	$K^{1.5}$	K^3
Contact Area Current Density J_C	$K^{1.5}$	K^3
Oxide Storage Cap C_{OX}	1/K	1/K
Oxide Storage Charge Q_{CRIT}	$1/K^2$	1/K
Oxide Field E_{OX}	1	K
Junction Capacitance C_J	1/K	$1/K^{1.5}$
Junction Storage Charge	$1/K^2$	$1/K^{1.5}$
Power Dissipation per Gate	$1/K^{1.5}$	K
Gate Delay t_D	$1/K^{1.5}$	$1/K^2$
Delay X Power	$1/K^3$	1/K

NOTES:
* Saturated Velocity Case: Term on right is for saturation limit.
** Improved Performance: Duty cycle = constant.

The reliability engineer must have an understanding of reliability failure mechanisms. Overall, the Technology Development Quality and Reliability group focuses on the fundamental reliability of the process: wearout prevention; determination of reliability-related layout design rules; reliability analysis of device structures and materials; characterization control and screening of latent defect density; and fundamental studies of failure physics. This group performs the reliability certification evaluations on both test pattern structures and large integrated test vehicles such as memories and microprocessors.

Precertification Requirements

Before a new process technology can be certified, a number of activities must be completed. First, an upfront risk assessment is performed to identify issues that may limit our ability to design and deliver products which meet performance, quality, reliability, cost and manufacturability goals. Then the Technology Development (TD) group develops a plan for evaluating the process modules. This plan looks at material composition uniformity, required thickness and machine operating parameters. Test structures are designed to examine various technology features and determine performance tradeoffs. The TD Quality and Reliability group identifies the potential reliability concerns and determines how to evaluate them.

The goal here is to get some process performance data and feedback on the reliability fundamentals so we can determine whether or not the new technology is feasible. If it is, a preliminary set of design rules is drafted so a process certification vehicle can be designed. This vehicle might not be a marketable product. Its primary function is to serve as a yield and reliability vehicle; therefore, it is designed to be easy to test and analyze for failures.

At this point we have some feasibility data, a potential certification vehicle, test structures for evaluating reliability and process module performance, and process and reliability performance goals. Next, a process certification plan is written. We are then ready to begin the process certification itself.

Early Certification Work

The most critical early reliability activity concerns fundamental wearout failure mechanisms. The mechanisms of general concern are:

- ?? Contact, via and metallization electromigration.
- ?? Threshold voltage stability.
- ?? Oxide wearout.
- ?? Hot electron and hole injection-induced shifts.
- ?? Moisture performance.

Wearout mechanisms, by nature, are difficult to test on the actual product. Since the product does not function properly under the high temperature, voltage or current required to test these mechanisms, special test structures are needed. However, a solid understanding of reliability physics and the actual circuit layout and operating conditions is needed to relate the accelerated data to how the product will perform in actual use. Since wearout prevention can often require changes to design rules (e.g., for maximum current in a metal line), these studies are begun as early as possible.

Since the wearout studies are ongoing during this stage, it is unlikely that the process or design rules are frozen. The process modules are still being characterized for possible improvement. The lead product reliability and yield data are limited but sufficient to determine progress on the technology learning curve.

Prototype sample shipments are released if the new technology:

- ?? Has no wearout issues, or there is a plan for addressing them.
- ?? Has reasonable yields and product reliability as judged by the learning curve.
- ?? Is actively improving open issues on the process modules and design rules.

Middle-Stage Certification Work

During the next stage of technology development, the lead vehicle is used to characterize and improve the process. In-line process monitors are used to monitor key parameters, and the process is optimized to raise the capability of the individual process steps. Test structures are used to do this for device characteristics. Much emphasis is placed on optimizing the process for yield enhancement. Wearout studies continue on a larger sample of material to establish a solid baseline encompassing a full range of process variation. The process may be intentionally skewed to ensure that reliability goals are met even at 3- or 4-sigma process corners.

More fabrication lots of the lead vehicle are run through the product reliability stresses in order to gather some statistically significant reliability data. All failing devices are subjected to failure analysis to determine the root cause and corrective actions so the process can be improved. At this point, we have substantial information suggesting that the process will be able to meet the requirements for certification, but complete robustness will not have been proven.

It is during this level of the certification plan that nonprototype units are shipped. For this to occur, the process must meet the following requirements:

?? Wearout issues are resolved.
?? The process is fairly stable.
?? The process is under statistical process control.
?? All changes are managed through the Process Change Control Board (PCCB) as part of the change control system.
?? Infant mortality fallout is known and screenable.
?? The production burn-in is defined.
?? The long-term failure rate meets the learning curve goals.
?? There is a written plan for continuous improvement.
?? Reliability and manufacturability monitors are in place.

In general, the process is not fully certified because we have not completed all the reliability testing, nor have all the manufacturability issues been resolved. Device and reliability performances are meeting our goals, although extra screening might be in use until the root causes are fixed.

During this period and throughout the certification effort, reliability and manufacturability data are continuously being generated. As we gather more data, our confidence in the quality and reliability of the material goes up, and we begin to ship more early material to our customers. As with any customer shipments, regardless of our own internal certification status, this early material must meet our customers' requirements. It is during this period that our customers start their own qualifications.

Technology Certification

At certification, the reliability stresses are complete and demonstrate that the process is reliable. The process is stable except for the ongoing continuous improvement work that the manufacturing process engineering group is doing. All changes are fully under the control of the Process Change Control Board (PCCB). (Chapter 4 describes how changes are certified.) The process is under full statistical process control (SPC). There is an actively supported reliability monitor program that drives continuous improvement. This program affects not only the engineering and manufacturing areas of fab, but periodically requires improvements in design, test and assembly.

The technology is reliable and manufacturable, and it is fully ramped into volume production. It may fall under the responsibility of a manufacturing fabrication site, or it may be ramped in place in the original development site.

PACKAGE DEVELOPMENT AND CERTIFICATION

Introduction

Significant changes are occurring in integrated circuit packaging. The continuing demand for higher-performance products is requiring levels of package performance unattainable by the molded plastic and ceramic packages of the past decade.

Increased complexity and operating speeds are driving pin counts higher to accommodate I/O as well as power and ground connections. The increased density and transistor count translates to higher power and thermal dissipation requirements. Higher operating speeds require the package to provide reduced crosstalk and noise.

These changes in design, materials and form factor pose a number of challenges to both the technology developer and the reliability engineer. New materials need to be evaluated to ensure that they perform in a robust manner over the expected life of the product. They must also perform across a broad range of environmental conditions. Just as important, the material and design must be proven stable during the manufacturing processes.

Package Engineering Reliability Goals

Packages are developed to serve a wide range of products and silicon technologies. It is important to ensure that the package technology “envelope” is capable of encompassing all planned products. Thus, development focuses on thoroughly understanding the limits of the package rather than on simply ensuring that it will perform flawlessly for a single product. Prior to initiating development, Intel’s Technology Development organization defines the envelope in a document known as the Technology Target Specification (TTS). The envelope goals are developed and agreed to by the Technology Development team, their product development customers and reliability engineering, and become the roadmap for the technology. This roadmap contains package, material, manufacturing and quality/reliability performance goals. Once agreed to, development commences.

Assembly Technology Development (ATD) is linked to many other development organizations, as shown earlier in Figure 3-1. Silicon Technology provides test chips and product die. Die coatings, metal and interlayer dielectric (ILD) layers, and scribe street design are only a few of the areas that require organizations to work closely together in order to ensure a robust end product. Test Technology provides the handling and electrical test capability. Design Technology ensures that product performance metrics are encompassed in the package design. ATD also works closely with the factories to ensure that the new process is manufacturable and provides high reliability and yields. Reliability engineers from each of these organizations ensure coordinated reliability plans with appropriate reviews.

Reliability data is collected throughout the development phase. As mentioned earlier, the goal is to ensure a robust technology envelope. Thus, reliability stresses are designed to provide information on the weak links in the package and process. Stressing takes the package well beyond the environment we expect it to encounter in normal field use (see Figure 3-2).

The failure information acquired is fed back to the development team, allowing them to make modifications in materials and processes to improve robustness. This approach also ensures low-risk product qualifications. The process, referred to as continuous certification, is repeated many times during the development phase. The data generated is collected for future reference in databases referred to as baselines, which are used to gauge progress and as benchmarks for future process and material improvements. Figure 3-3 illustrates the continuous certification processes.

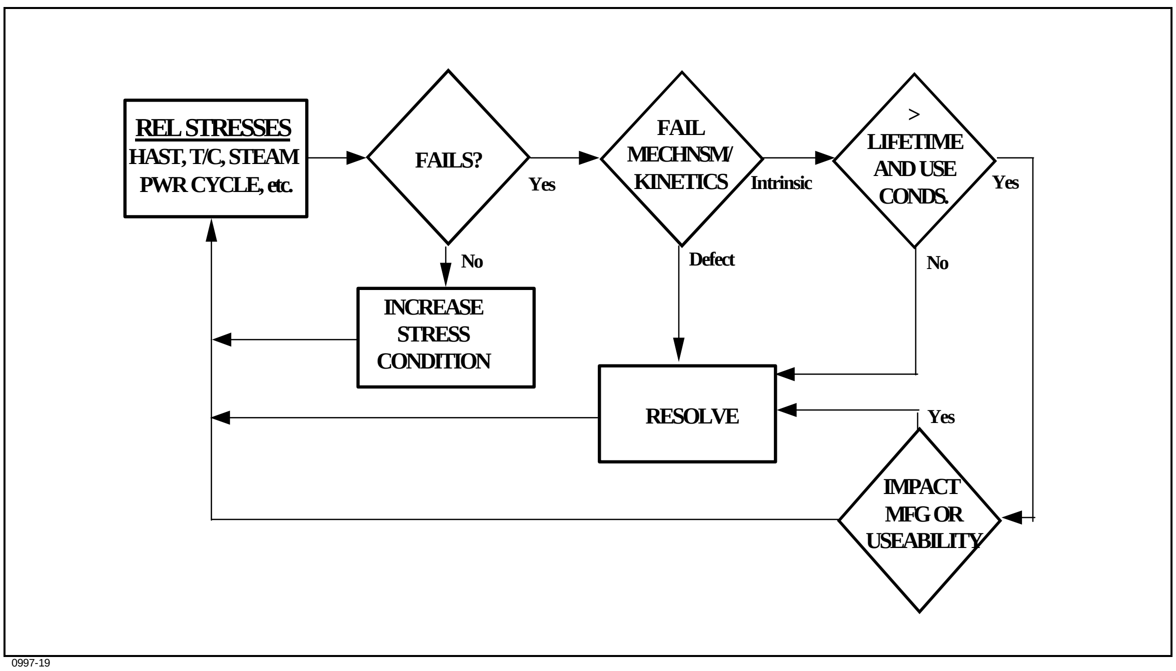

Figure 3-2. Reliability Stress Approach

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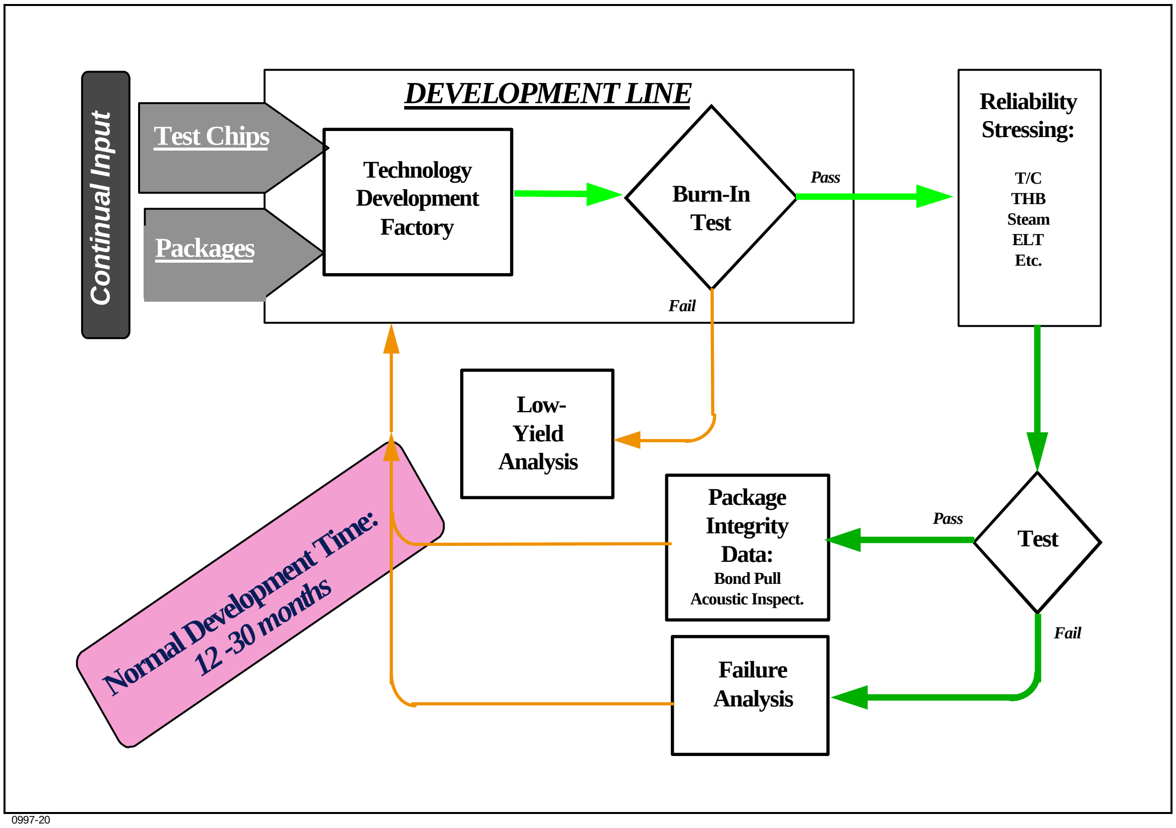

Figure 3-3. Continuous Certification

ASSEMBLY DEVELOPMENT

Introduction

Two organizations drive assembly development at Intel: Assembly Technology Development (ATD), which is responsible for leading-edge microprocessors; and the Manufacturing Technology and Development group, which focuses on system and board products. ATD consists of package technology development engineering, infrastructure groups such as the Technology Development manufacturing line, and core competency groups including design, low-yield analysis and polymer development. The Manufacturing Technology and Development group comprises development engineers from a variety of support groups with core competencies that include design for manufacturability, soldering, joining technology and component placement development.

Quality and reliability support is provided by TD Quality and Reliability and is focused specifically on assembly development. The quality and reliability engineers (QREs) work as members of various package or assembly development teams, and report to both the Quality and Reliability and development management structures.

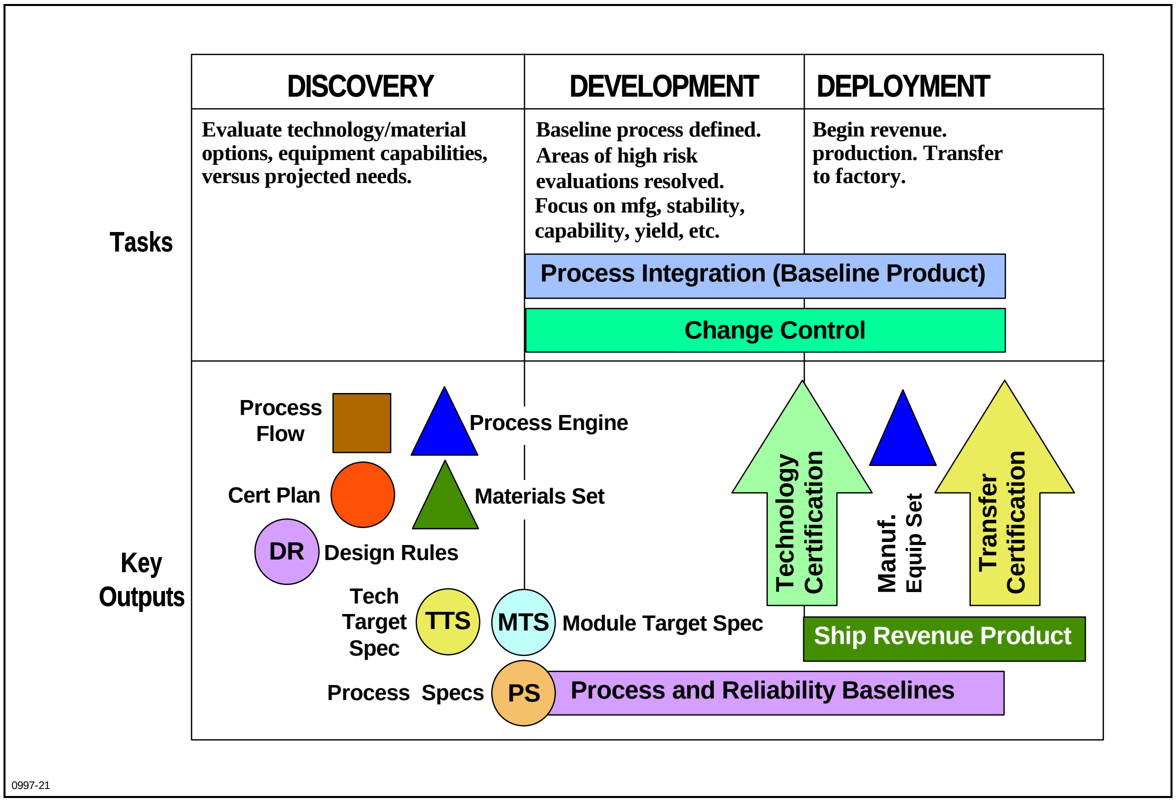

Figure 3-4. Technology Development

Discovery Phase

The development of a new assembly technology occurs in three distinct phases: discovery, development and deployment (see Figure 3-4). During discovery, product needs, design, material, process and equipment options are evaluated. Technology and business plans are developed to satisfy the Technology Target Spec. Based on a technology assessment and corporate guidelines, a certification plan outlining the reliability requirements is also developed during the discovery phase. During this period, technologists determine if the needed materials and infrastructure exist or can be developed in time to support the targeted package. A process flow is developed and a technology assessment is conducted to identify areas of high risk in the materials, process and reliability arenas. Plans are generated to address identified areas of concern.

Package and silicon developers work closely to design and fabricate the assembly test chip to be used in development. This chip contains circuitry that specifically aids in the debug of the package, including opens, shorts, leakage and thermal circuitry. It is the same size as or larger than the targeted product and uses the same process. As soon as a base capability exists, packages are built and submitted to reliability stress to determine weaknesses, validate the technology assessment and initiate the various data baselines, such as yield and

reliability. The initial reliability data helps determine the overall capabilities of the material and the process. Stress-to-fail techniques are used either by extending the stress duration or by increasing the severity of the stress conditions themselves. Based on this, material, process or design changes are made as needed.

Development Phase

At the completion of the discovery phase, a determination is made to move to the development phase. This decision is based on the learning acquired during discovery and an updated technology risk assessment. The development phase is the period in which the package/board technology is thoroughly exercised. Continuous certification is used rigorously to drive improvements in process and material capability, stability, reliability and manufacturability. Technology certification caps the development phase, signifying that the technology meets or surpasses the targets set in the Technology Target Specification and certification plan.

Early in this phase, production equipment is specified and installed in the development factory. The process flow is updated based on improvements made during the discovery phase. The initial baseline process is documented. Each process module develops a target spec detailing expected manufacturing, yield and reliability goals. Once the equipment is in place and the process is established, a passive data collection (PDC) exercise is conducted. Each process module runs at least 30 lots of material without making any process changes or adjustments. Upon completion, the data is analyzed and a determination is made about the stability and capability of the process. PDCs are also conducted at Intel's material suppliers to establish the capability and stability of their processes. Process change control is implemented at both Intel and suppliers. All proposed changes require a documented request for change, or preliminary white paper, describing the change, the reason for it and the data that will be collected to validate it. If approved by the Change Control Board (CCB), the data is collected in an engineering mode. The requester documents the results in a final white paper. If approved by the CCB, the change is implemented.

Packages and boards are continuously built in the development factory, ensuring a continuous flow of data to the various databases. During a normal package development effort, more than 100,000 packages will be built, with approximately 10% of them submitted for reliability stressing. Findings are continuously fed back to the process, as shown in Figure 3-3. The development phase is completed and technology certification achieved when the targets established in the TTS and Module Target Specification (MTS) are met. The MTS is a document for each process module that specifies module requirements and goals in terms of performance against design rules (e.g., Cpk, defect density, quality and reliability). TTS and MTS targets include reliability, manufacturing and yield goals.

Deployment Phase

During deployment, the technology is ramped in the development factory and then transferred to a high-volume manufacturing plant. Continued focus on yield, manufacturability and reliability is maintained. Successful transfer is signified by the achievement of a transfer certification. At this point, technology ownership transfers from the development to the factory organizations.

During development, a Mutual Expectations Document, outlining the requirements for transfer to the factory, is co-developed by Technology Development and the receiving factory, providing a transfer roadmap. Development works to ensure that the factory copies the equipment set and process. Once the process is established, the factory performs a passive data collection to ensure stability, capability and a match with the development baselines. The technology is certified at the factory based on yield, reliability and manufacturing data. The expectation of these metrics is a match with the baselines established during development. Reliability and yield monitors are established to ensure consistent quality and reliability. Development engineering personnel work closely with the factory to ensure maximum learning.

PRODUCT DEVELOPMENT

Introduction

The product development cycle parallels that of packages and processes. The development team's major goal is to design a product that meets functionality and performance targets, requires no modifications to the process or package, and has quality and reliability consistent with the capabilities of the processes used to create and manufacture it. As with all of the development efforts discussed in this chapter, the goal is a manufacturable, reliable product that satisfies customer needs. As Figure 3-5 illustrates, increasing design complexity, coupled with the process complexity discussed in the first half of this chapter, makes meeting these goals quite challenging.

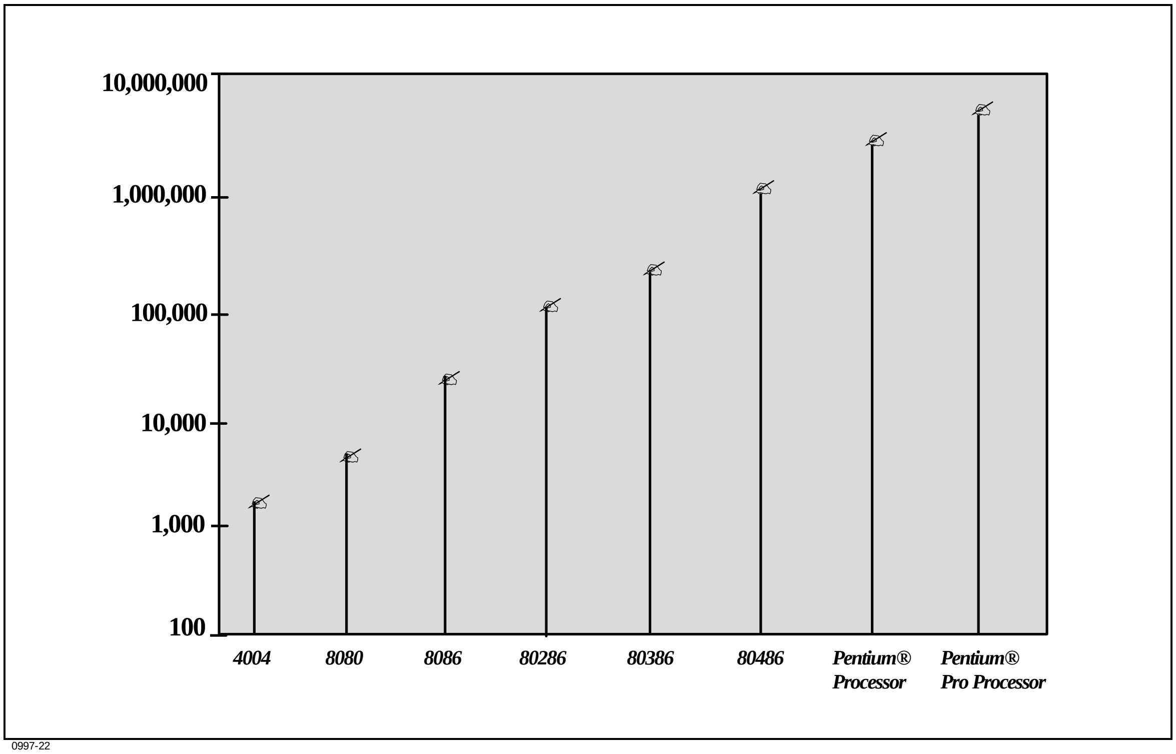

Figure 3-5. Increase in Product Device Count

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Product Development Quality and Reliability Engineering

Intel has three major quality and reliability engineering functions that focus on product development, including design, test and validation. These engineers partner with Design Engineering, Product Engineering and Design Technology groups to ensure that quality and reliability are comprehensively built in and validated.

?? **Product quality and reliability engineers (PQREs) and product development quality engineers (PDQEs)** support Intel's business units by ensuring that all necessary ingredients are in place for high-quality, high-reliability products. PQREs and PDQEs are members of product development teams and are responsible for setting product quality and reliability goals. They also ensure that Design for Quality and Reliability best-known methods and features are correctly implemented; plan and execute quality and reliability validation; and work with manufacturing and technology groups to prevent and resolve quality and reliability issues.

?? **Failure analysis engineers** are responsible for delivering and utilizing state-of-the-art failure analysis and debug technologies. FA engineers work with Intel's product development community to use these tools and methods to understand the causes of limiters to product quality and reliability. The increasing complexity of product designs and rapid process scaling demand innovative tools and techniques for quickly and successfully resolving product quality and reliability issues.

?? **Product development technology quality and reliability engineers (PDT QRE**s) support Intel's design and test technology groups in the delivery of tools and methodologies that enable quality and reliability to be built in "upstream," i.e., during design and test program development. The PDT QRE groups also manage Intel's product qualification systems, with responsibility for establishing corporate quality and reliability requirements and ensuring that associated metrology is in place.

Designing In Quality and Reliability

Design for Quality and Reliability (DFQR) is the collection of tools and methods that enables Intel to design quality and reliability into new products. The primary effect of DFQR on our new products is that product validation is moved up to the design phase from the traditional back-end, product qualification phase. Examples include accurate electromigration and hot-electron checking to prevent problems that would otherwise be detected during finished product qualification. The benefit of DFQR is faster time to product quality and reliability. For Intel's customers, this means lower risk, especially during the initial production ramp.

DFQR addresses four key areas:

?? **Design for Quality.** This includes design features and design validation steps that enable and accelerate compliance to product quality and functionality requirements. Examples include Design for Test (DFT), circuit insertion, test program coverage assurance, IDDQ compatibility, design margin (voltage, temperature and frequency), logic validation and performance verification.

?? **Design for Reliability.** Reliability verification (RV) during design addresses reliability upstream. Examples include the use of automated CAD capabilities to ensure that electromigration, hot electron, electrostatic discharge (ESD), latch-up and thin-film

cracking design rules are met. Additional examples are board- and system-level failure analysis, redundant system design and fail-safe design.

?? **Design for Validatio**n. The goal of DFV is to implement design features that facilitate comprehensive and faster validation, fault isolation and analysis. Examples are placement of probe points, non-intrusive accessibility to critical signals (e.g., scan, direct access test), design-in of memory rastering capability, board-level sockets, voltage and frequency margin hooks.

?? **Design for Manufacturability.** This area addresses design features and verification steps that facilitate high-volume manufacturing. Design rule checkers (DRCs) for wafer fab/boards, assembly and test design rules are run during design. Examples include metal spacing, package compatibility and interconnect "antennae." In addition, Design for Burn-in features (e.g., built-in self-test) that enable manufacturable infant mortality screening in production are designed in.

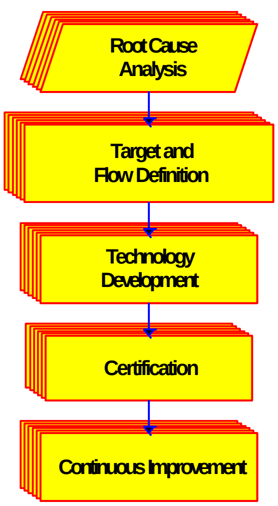

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Figure 3-6. Development and Certification Flow for DFQR Systems and Tools

For each of these areas, Intel applies the technology certification approach used for silicon and assembly technologies. This ensures to a high degree of confidence that our DFQR technologies are effective at identifying and addressing true quality and reliability limiters during design. Certification is synchronized with Intel's CAD generations and silicon technology. This approach drives the continuous improvement and risk reduction of new and existing DFQR capabilities. Figure 3-6 illustrates Intel's DFQR certification approach.

After DFQR capabilities are certified, we begin implementation by planning their use during the product planning phase. It then progresses through several formal intermediate design reviews during the design phase and culminates in final audits toward the end of the design cycle. Systems to ensure compliance are in the form of design checklists and are utilized through active partnership between product QRE and design engineers. Tools that have been integrated into Intel's product planning and design flows include resource estimation; methods for design, test pattern reviews and audits; and tape out checklists.

PRODUCT QUALIFICATION

Introduction

To ensure that all upstream technology and product development quality and reliability efforts produce high-quality products, Intel has a disciplined and consistent product qualification methodology. Intel product qualifications consist of three major qualification levels designed to meet the product introduction and production ramp needs of Intel and its customers.

?? **Prototype Qualification** is intended for initial desig***n***-in and prototypes.
?? **Production Qualification** is intended for early production and formal customer qualifications.
?? **Full Qualification** is intended for full production and unlimited shipments.

At any of the three qualification levels, there can be no indications of issues with potentially serious ramifications for Intel or our customers. The only difference between the three levels is the amount of qualification data that is available to confirm decreasing risk and thus increased confidence in product health. Figure 3-7 shows how each qualification level is related to risk.

Prototype Qualification

Prototype Qualification is the first qualification level. Products at this level are considered medium risk. Prototype Qualification material is released into the market to meet a customer's design-in and prototyping needs and to provide early application feedback. These are the first products produced for revenue shipment using formal manufacturing and test.

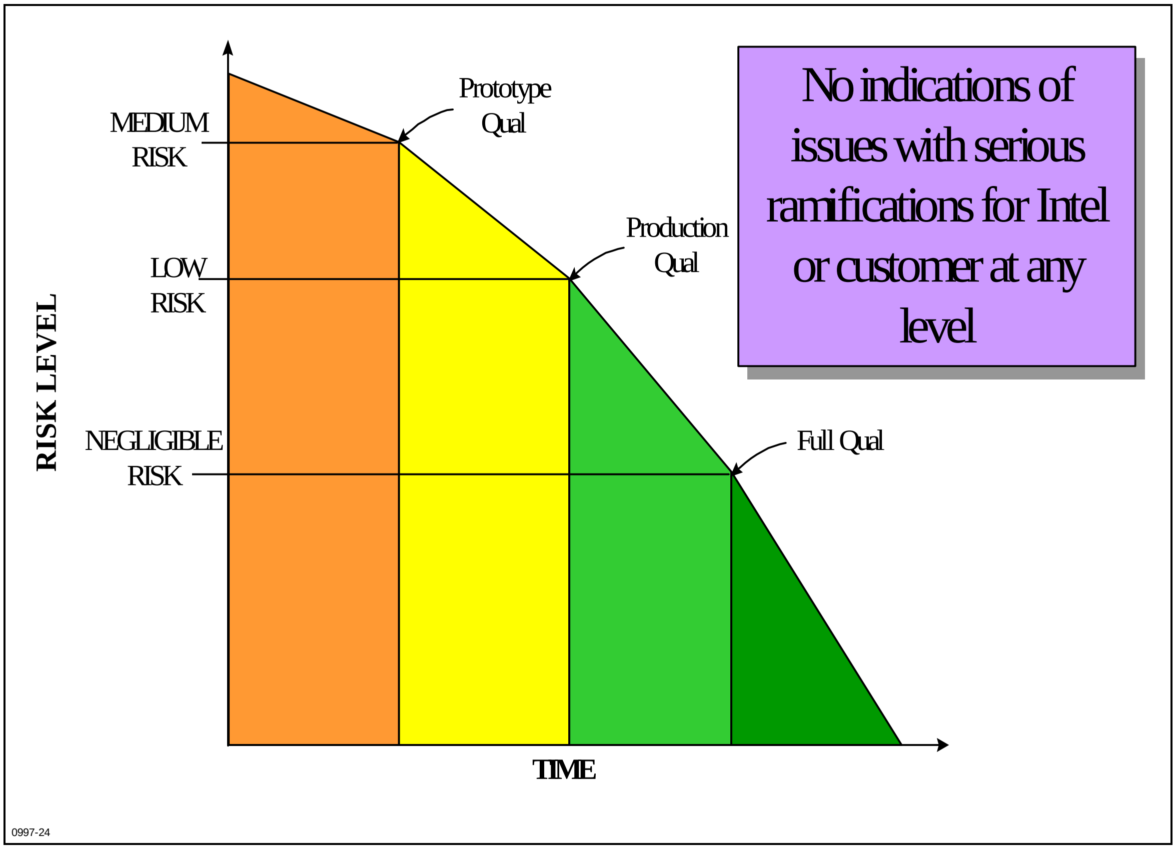

Figure 3-7. Product Qualification Risk Curve

Two special customer information guidelines are associated with Prototype Qualification. First, significant changes to the manufacturing, design or testing are possible since there is very little quality and reliability data available at this time. Second, Prototype Qualification targets are somewhat limited as compared to Production and Full Qualification targets, and there is moderate risk associated with purchasing product at this qualification level. It is not recommended that these early products be used for customer qualification.

Production Qualification

Production Qualification is intended to be a transitional level from Prototype Qualification to Full Qualification. Products at Production Qualification are considered low risk. While not all of the testing is complete at this level, there is sufficient data to indicate that the product can meet customer application needs. Customer qualifications and construction analysis can begin at this level. Production Qualification requirements are more comprehensive than those for Prototype Qualification.

Full Qualification

Full Qualification is the highest qualification level. Products at Full Qualification are considered to have negligible risk. Closure of all corrective actions is complete or in the process of completion. Final postmortems have been scheduled or held.

Product Qualification Methodology

Figure 3-8 illustrates Intel's product qualification methodology. There are three major parts of the methodology: target setting, risk assessment and qualification plan development and execution. Minimum qualification targets or requirements are enhanced and augmented by three subsequent processes to arrive at a customized product-specific target list. Once the target list is completed, it is transferred to the Product Qualification Risk Scorecard and an initial risk assessment is performed. The actual qualification plan is developed from the target list and initial risk assessment. The results of qualification execution are tracked and recorded on the scorecard. Risk corrective action plans are used to manage critical risk areas as indicated by the scorecard and the qualification decision-making process. A pre-qualification is generally performed to promote anticipation of problems and proactive resolution before the actual qualification begins. At the end of the qualification exercise, a postmortem analysis is required in order to promote continuous improvement of the product development process.

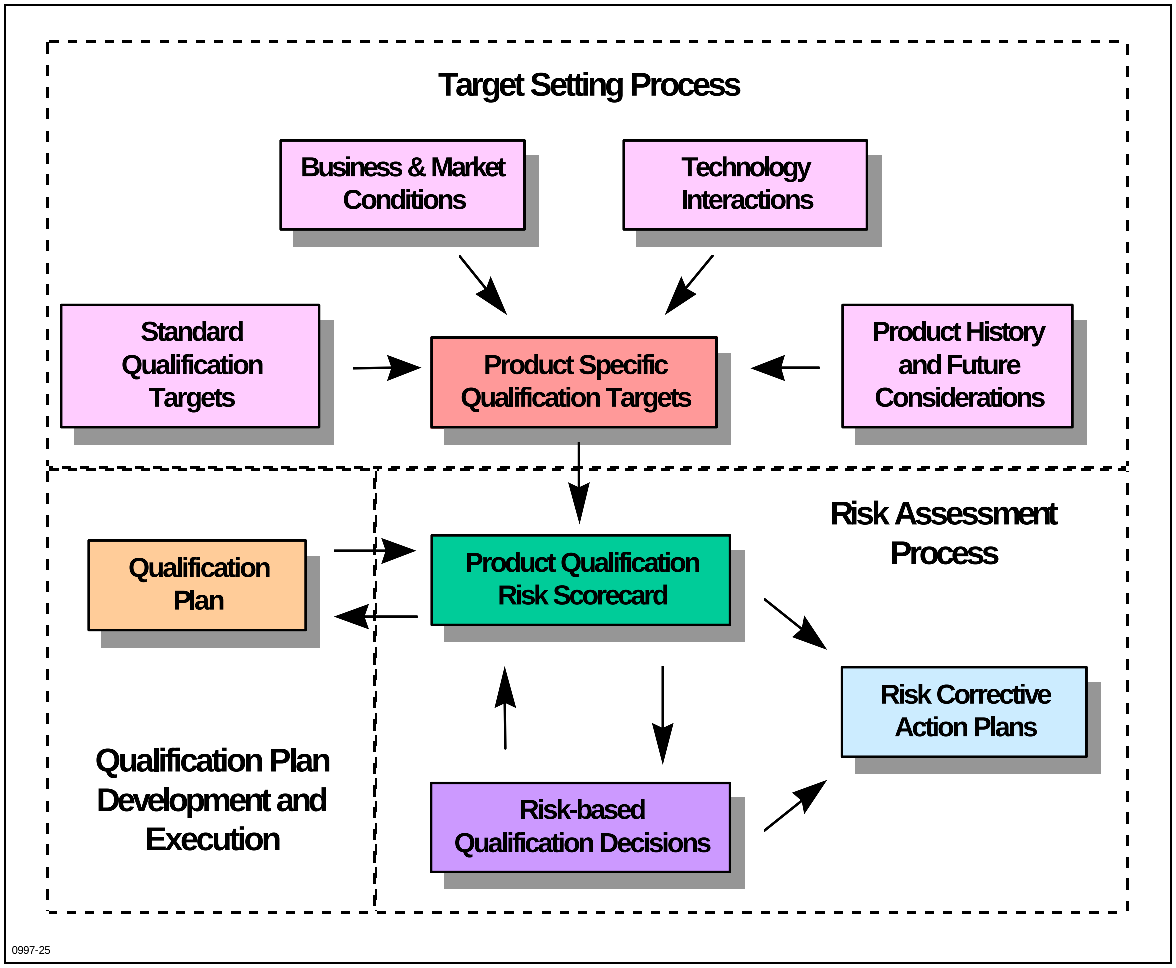

Figure 3-8. Product Qualification Methodology Model

Intel's Qualification Organization

Intel's product qualification systems are managed by a network of Intel quality and reliability managers and engineers representing each business unit and technology development group. Inputs from customers (via Intel's Customer Quality and Reliability group), business units, Technology Development and manufacturing groups are solicited and integrated.

This network formulates and synergizes high-level qualification and certification policies; determines market-driven corporate quality and reliability requirements and methodologies for product qualifications; and addresses interactions between technology certification, product qualification, manufacturing and customer quality systems. Another vital responsibility is to monitor the effectiveness of Intel's qualification systems (e.g., success and escape rates), and to drive improvements accordingly in validation, upstream development and manufacturing processes.

Consistent compliance to Intel's qualification systems is reinforced by local teams of experienced quality and reliability engineers, who review all new product qualification plans

and decisions with respect to documented standards, and provide feedback and direction. These teams are also responsible for closing the loop with higher-level qualification systems owners to ensure that specific issues are captured and resolved.

CONCLUSION

Each successive generation of Intel technology poses a new set of quality and reliability challenges. To meet these challenges, we're continually upgrading our design and development methodologies, with an emphasis on ongoing risk assessment and synchronization of the various sub-technologies that support each new generation.

By identifying opportunities for improvement as early as possible during development, and by driving supporting technologies to the same level of maturity with respect to product development and introduction, Intel can bring new products quickly to market in support of customers' evolving application needs. What's more, we can offer an increasingly higher cost performance benefit.

4

Manufacturing Quality System

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CHAPTER 4
MANUFACTURING QUALITY SYSTEM

INTRODUCTION

With defect levels that are the lowest or among the lowest in the industry, we are proud of the product we manufacture at Intel. Continuous improvement methodologies are such an ingrained part of our manufacturing process that we've easily achieved ISO 9002 registration for all of our mature factories. We now use ISO 9000 as the baseline quality system throughout our factories worldwide.

Working in tandem with the SEMATECH consortium and our customers, Intel has access to the most up-to-date industry techniques and applies them wherever appropriate. Moreover, internally we develop unique methods to continuously boost our product quality and reliability. Our leading-edge product development efforts continue to drive the innovation and adoption of increasingly effective manufacturing methods.

In this chapter, you'll find an overview of our Manufacturing Quality System. This system encompasses all of Intel's products, from silicon and components to boards, systems and modules. In keeping with our commitment to ISO 9000 as our quality baseline, we've referenced the components of our Manufacturing Quality System by their corresponding ISO elements:

?? Process control.
?? Inspection and testing.
?? Material supplier quality.
?? Subcontractor quality.
?? Control of inspection, measuring and test equipment.
?? Control of nonconforming product.
?? Corrective and preventive action.
?? Handling, storage, packaging and delivery.
?? Product identification and traceability.
?? Control of quality records.
?? Internal quality audits.
?? Statistical techniques.
?? Document control.
?? Training

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MANUFACTURING ORGANIZATION

Intel's manufacturing organization encompasses wafer fabrication, assembly and high-volume testing. Geographically dispersed, this organization has wafer fabrication facilities in eight U.S. sites, Ireland and Israel. It also includes assembly locations and manufacturing test facilities in the United States, Malaysia, Puerto Rico, Costa Rica, China, Ireland and the Philippines. Additionally, design centers are located in the United States, Japan, Israel and Malaysia.

To support these various facilities, the manufacturing Quality and Reliability organization is also dispersed. At each manufacturing site, a Quality and Reliability staff monitors quality, provides feedback to the manufacturing and Technology Development organizations and participates in problem solving. These local Quality and Reliability organizations report jointly to local site management and Corporate Quality Network management in a matrixed relationship that provides the flexibility to meet local needs while maintaining policy consistency across Intel.

The local organizations have the responsibility and authority to:

??Identify and record problems and corrective actions.

??Initiate and provide solutions.

??Verify implementation of solutions.

??Control nonconforming products until deficiencies are corrected.

??Initiate actions to prevent nonconformities.

??Share information and best-known methods across the geographically dispersed organizations.

PROCESS CONTROL

Introduction

Process Technology Development (Process TD) stays with each new process through transfer to manufacturing until process control, high volume and yield targets have been achieved. Early on, we select significant process/product parameters for statistical control and document detailed process/product control plans. We also employ a station owner approach that empowers factory employees to own station quality and statistical control of all key parameters. With this approach, they can use reaction plans and process control decision trees to address process interruptions and out-of-statistical-control situations.

What's more, a system of daily, weekly and monthly reviews addresses any adverse trends, excursions or deficiencies to goals. We then empower process-oriented teams to make improvements that will bring the process to manufacturability and statistical control goals. Figure 4-1 illustrates the development of process capability for the critical parameter of transistor threshold.

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Our product validation process includes several formal reviews of design, test, quality, reliability and manufacturability before volume production begins. Often this process also includes customer reviews. In-line process control monitoring is ongoing, as we track significant parameters using tools such as control charts (see example in Figure 4-2). Increasingly, station-manufacturing statistical process control (SPC) is performed with a real-time, computer-based capability.

Real-time operator inspections and monitoring of key parameters allow immediate corrective action when process drifts occur. The use of SPC ensures that continuous process control is maintained. Manufacturing technicians and engineers use specific reaction plans and decision trees in succession to address process interruptions and significant out-of-statistical-control indications.

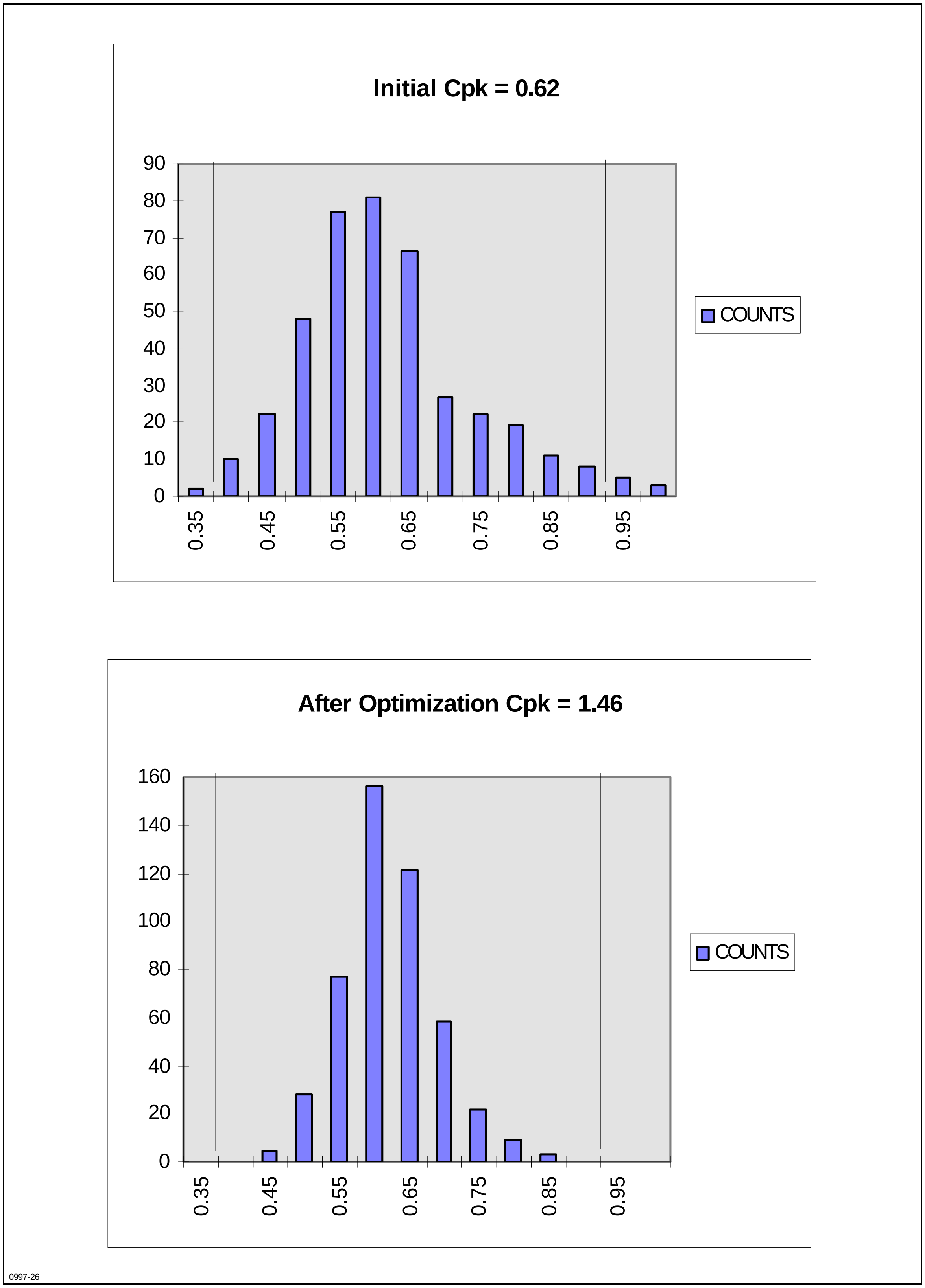

Figure 4-1. Improvement in Cpk

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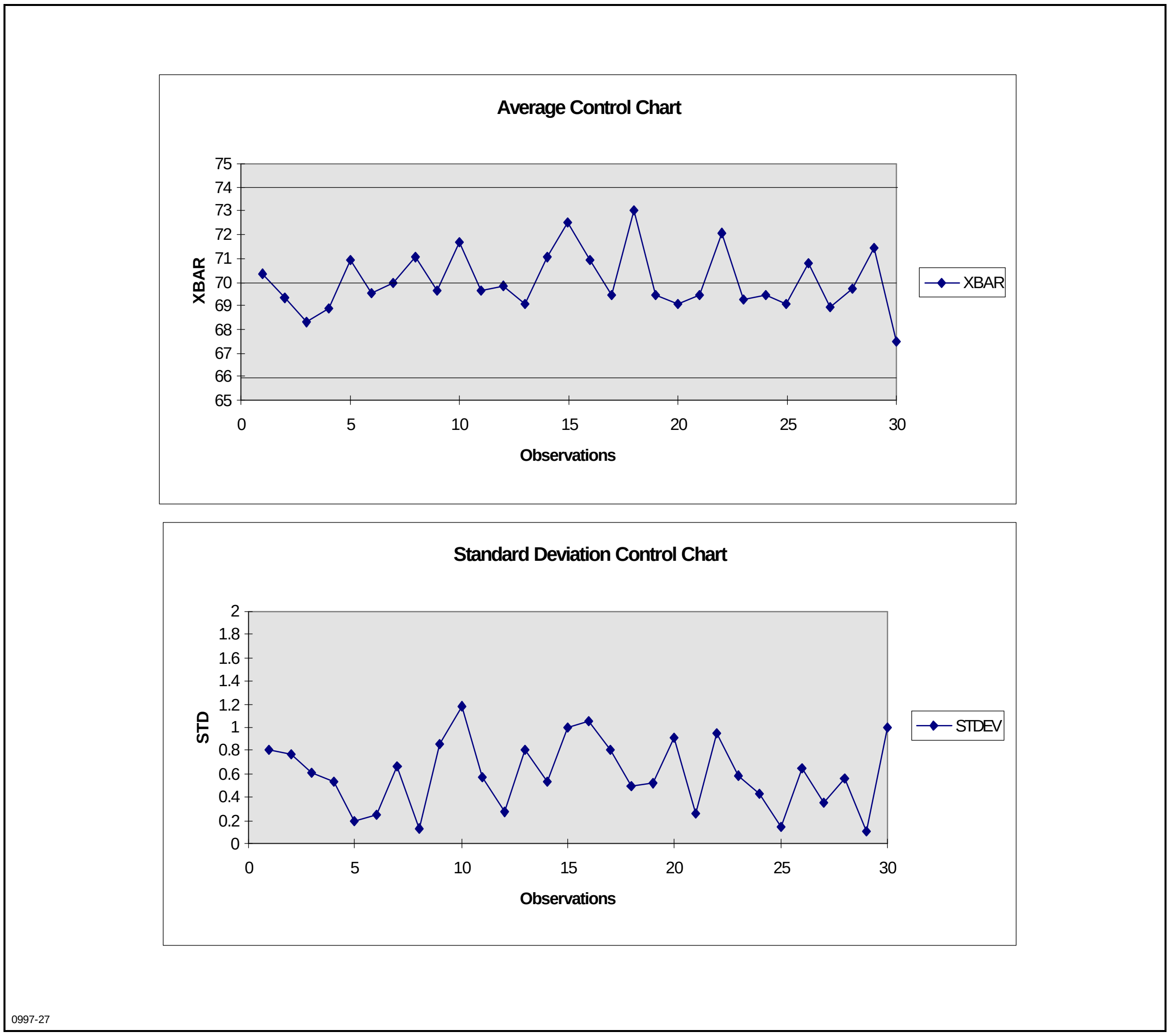

Figure 4-2. Control Charts

Continuous Improvement of Products and Services

As part of Process TD efforts and as an ongoing manufacturing improvement activity, Intel uses statistical analysis to evaluate each process step and its process control design. This analysis is key to identifying opportunities for process control improvement. In addition, we look closely at customer feedback, competitive analysis, sources of variation in the manufacturing process, and targets for world-class levels of quality, reliability, yield and throughput time. One highly effective approach for improvement is cause-effect analysis, which ensures that the root cause of a problem or the variation under attack is addressed and corrected. An example of an Ishikawa (or fishbone) diagram used in cause-effect analysis is shown in Figure 4-3.

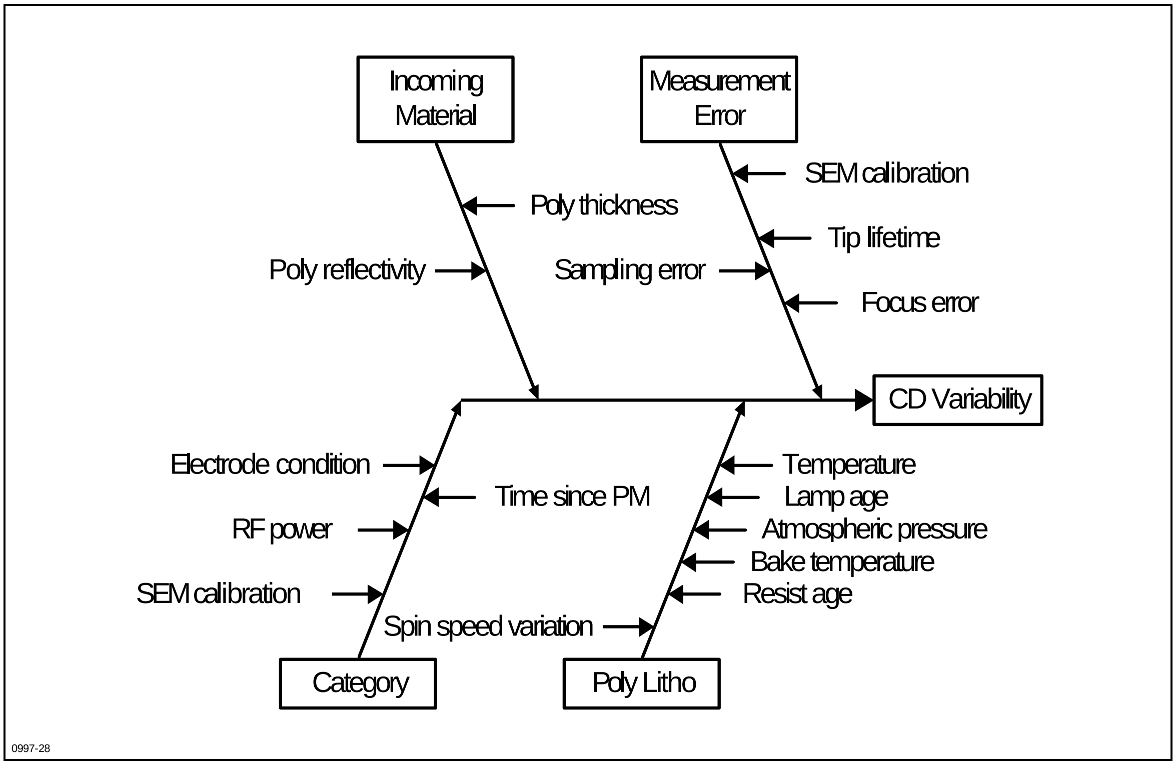

Figure 4-3. Example of Ishikawa Diagram

The Technology Development organization's yield engineers and manufacturing process/product engineers continually focus on defect reduction and process margin improvement. As an example, Figure 4-4 shows a Pareto chart used by Intel fabs to analyze the yield impact of metal particles from various process steps.

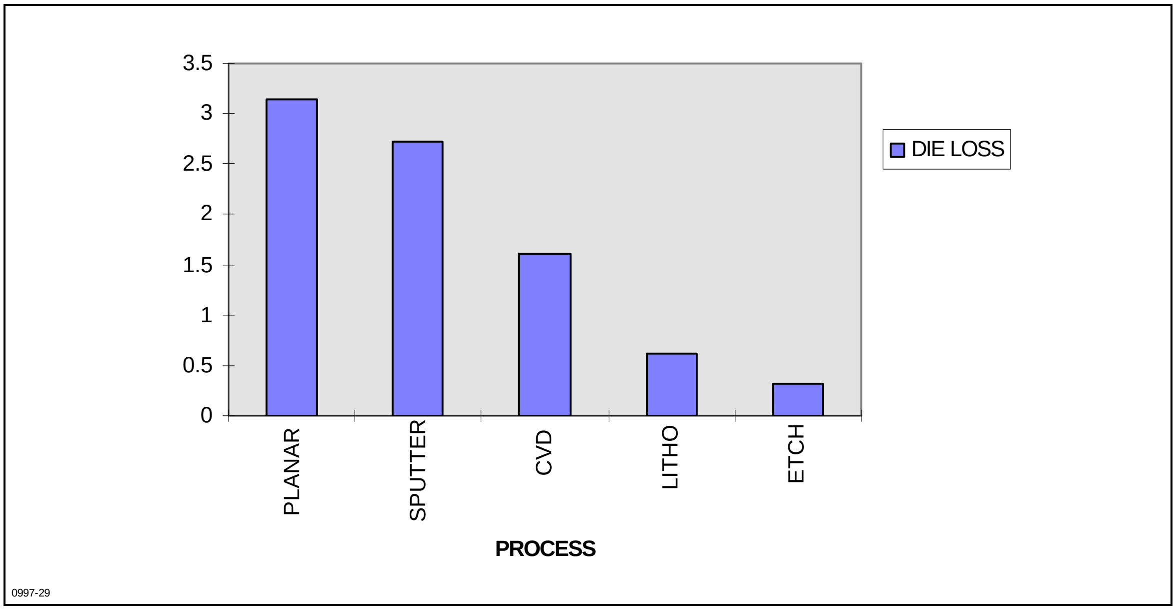

Figure 4-4. Metal Defects Pareto

Using SPC as a tool, we strive for reduced variability of key parameters for all of our manufacturing and job processes/products. Our SPC implementation, begun in the early 1980s, initially focused on training classes and the engineering application of SPC tools, such as control charts, parameter characterizations, correlation studies and design of experiments. Later in the ’80s, SPC training became more widespread at Intel across wafer fab and component assembly sites. We successfully applied SPC to manufacturing process control with an emphasis on product characteristics and recognition of out-of-control situations. As a result, we achieved significant reductions in variability. By the early 1990s, our improvement focus was on SPC applications for process parameters and automation of data collection and analysis. System and board manufacturing is currently adopting SPC methodologies already in place across our components business, rapidly leveraging off a wide range of innovative systems.

Conversion Management

Because continuous improvement is key to Intel quality, changes and conversions in processes, products and manufacturing sites are ongoing. An extensive Change Management Network (see Figure 4-5) manages conversions from change inception through internal qualifications to customer notification and acceptance. The network manages all changes regardless of whether notification is required. Change Control Boards (CCBs) track conversions from change initiation through change implementation.

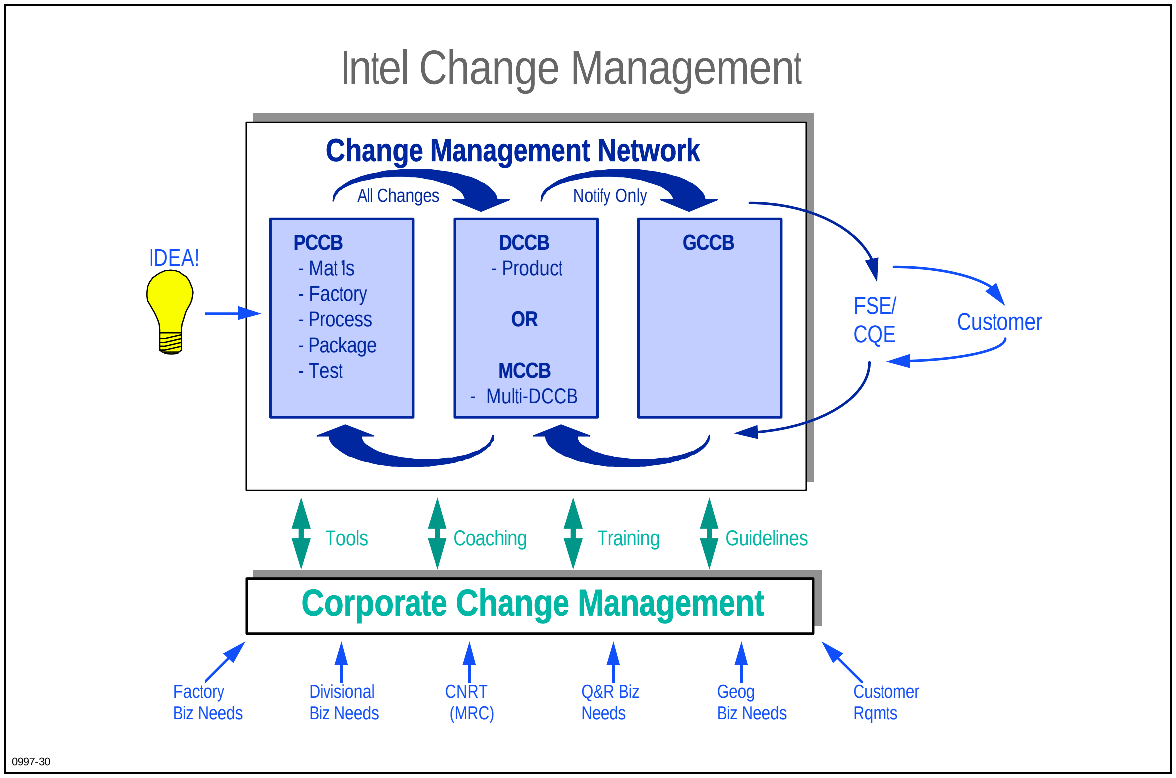

Figure 4-5. Intel Change Management

Change initiation triggers a product/process change in material or equipment. It can be used to sanction a new idea, determine the scope of the change and/or authorize resource commitment to support the proposed change.

Change implementation focuses on two areas: (1) enabling the production of new products utilizing new processes, and (2) discontinuing the manufacture of old products based on old processes. Change implementation encompasses internal qualification/validation activities and the dispositioning of old products, materials, equipment and processes. It also includes start-up of production on the new process and ensures end-customer readiness to receive the changed product.

An applicable Process Change Control Board (PCCB) reviews all changes. When multiple factories are running the same process, a common PCCB aligned by process across these factories is responsible for reviewing any process changes. This structure is crucial to ensuring equivalent product across all factory sites. Only those changes requiring customer notification are reviewed by the Divisional Change Control Board (DCCB) or Geographic Change Control Board (GCCB).

A key element of change review by PCCBs is the review and approval of the white paper. The white paper is the primary vehicle for internal, detailed communication of the proposed change. Key elements of a white paper include:

?? Conversion tracking ID.
?? Title of change.
?? Change description.
?? Reason for the change.
?? Products affected.
?? Key milestones.
?? Concerns and considerations.
?? Qualification plan.

All proposed changes, regardless of customer notification requirements, will have a white paper.

Equipment Qualification/Maintenance

The introduction of a new piece of manufacturing equipment begins in the corporate group chartered with qualifying new equipment. First, we validate the manufacturer's specifications and run a manufacturability exercise. Next, if the equipment meets the requirements for manufacturability, it is sent to a production area, which acts as a beta site. Only after passing the beta site criteria is equipment disseminated to other sites.

The extensiveness of the beta site criteria depends on the process step for which the equipment is designed. Each of these processes requires a certain performance, which forms part of the qualification criteria. Generally, qualification involves establishing machine control limits, in-line control criteria and finished product performance criteria (e.g., yields, speed, reliability).

The newer the piece of equipment, the more likely it is that in-line and offline product monitors will be used. As our knowledge base increases, we reduce the sample size and frequency, and use the equipment variables themselves as monitors.

The procedure for adding pieces of existing equipment for increased capacity is simpler than adding new equipment, but the process is basically the same. The first step is to ensure that the new piece of equipment behaves like the existing equipment. An exhaustive fingerprinting of the new equipment is run, ensuring that physical inputs such as gas flows and plumbing are identical to a prescribed limit.

Once the physical inputs have been matched for a new piece of equipment, we run process step monitors. Equipment qualification consists of matching the new tool to a reference tool using sequential statistical methods. This allows the equipment to be qualified as soon as matching is demonstrated.

After process step matching, module qualifications may be run. In these qualifications, we process material run through several process steps to check for interactions between the new piece of equipment and the installed base. Due to this meticulous matching process, such end-of-line events as electrical testing or class testing rarely uncover any equipment issues.

All equipment qualification changes are reviewed by appropriate Change Control Boards. These boards require the use of rigorous statistical methods, including sequential matching for equipment qualifications.

Once in the production environment, equipment undergoes preventive maintenance (PM) monitoring with a predetermined frequency. PM specifications detail equipment checks to be performed at regular intervals, and all actions are recorded so that performance of individual systems can be analyzed.

Environmental Control

INTRODUCTION

Intel’s commitment to the environment is an integral part of our success as a corporation. We’re currently working to make every step of our manufacturing process environmentally safe, from raw material extraction to product distribution and disposal. We’ve incorporated our Design for Environment (DFE) program as a key element in our environmental management system. The DFE program is based on the hierarchy of reducing, reusing, recycling and disposing of materials in an environmentally safe manner. The program is designed to conserve natural resources and reduce the environmental burden of waste generation and emissions to air, water and land by developing environmentally compatible products and processes.

Since 1989, for instance, we’ve reduced our use of ozone-depleting chemicals in manufacturing from 600,000 pounds per year to zero. We’ve eliminated the use of ethylene-based glycol ethers. In our latest wafer manufacturing process, we’ve reduced volatile organic compound emissions by 50% over previous process generations. Our circuit board cleaning operations, which initially used Freon 113 (an ozone-depleting substance), were converted to a water-based cleaning system and now are being converted to a no-clean system that requires no solvents or water.

MANUFACTURING ENVIRONMENT

Many environmental factors must be controlled to support high-yielding product in our factories. One of these factors is the air supplied to our cleanrooms. In our newer factories, we filter the air entering the process bays to contain less than one 0.?mm or larger particle per cubic foot. The air that enters a bay is also controlled for velocity and directionality so that particles generated in the cleanroom are quickly swept to the floor. Particle generation is minimized in the cleanroom through the use of bunny suits and cleanroom protocol. In addition, we supply enough air to the cleanroom to maintain positive pressure in relation to

the environment outside. The positive pressure prevents the backflow of contaminants into the cleanroom through doors and gaps in the ceilings, walls and floors.

Another factor controlled in Intel factories is relative humidity. We optimize relative humidity to accommodate operator comfort, static discharge (dry air prevents the natural leakage of static to the ground) and chemical processes. We also target temperature in the factory, primarily for operator comfort. However, some equipment in the factory is very sensitive to temperature changes, so a very narrow range of temperature fluctuation is allowed.

A final factor in manufacturing environmental control is electrical static build-up. The static cycle encompasses generation, accumulation and discharge. The accumulation of static charge is mitigated in our factories through the use of ceiling ionizers. The ionizers quickly neutralize any generated charge before discharge can occur, and thus help prevent damage to microprocessor circuitry.

INSPECTION AND TESTING

Introduction

As Intel products move through the manufacturing line, we inspect and test them to ensure that they meet the specifications they were designed for. The objective of our manufacturing and reliability monitors is to maintain statistical process control and to detect excursions.

Manufacturing Monitors

Manufacturing monitors are used extensively to control various fabrication and assembly processes. Each process step has a number of monitored variables. For example, a bonding operation might include machine controls (e.g., power, pressure, time, frequency) and finished product monitors (e.g., bond pulls, thermal cycling). In another example, for a photoresist development step these variables might be equipment-related (e.g., develop volume, water pressure, spin speed) and inspections-related (e.g., amount of residual resist, levels of contamination). We monitor anything that might affect the final product's general performance or factory flow.

Since processes, equipment and products are constantly changing, the monitoring program is always evolving. Our ongoing learning changes the way we monitor our fab and assembly processes. Sometimes we eliminate a monitor or replace it with a more effective one because it is no longer needed. At other times, we add monitors to address problems until appropriate fixes are implemented.

The goal for our manufacturing monitors is to operate under statistical control. In Intel factories, statistical process control (SPC) is a feedback system that provides information to engineering and manufacturing about how processes are running. This allows us to identify problems early and prevent excursions.

Reliability Monitors

Process reliability monitors are a subset of Intel's manufacturing monitors. They are executed in-line or offline as needed in wafer fabrication and assembly processes. The rest of the reliability monitors come from the reliability certification process. These include the fundamental wearout stresses, which are typically run on special test structures, and the environmental stresses, which are used to measure reliability performance on the finished or semi-finished product.

We implement certain reliability screens during electrical testing, either during wafer-sort testing or finished product testing. These include margin screens, such as for guardbanding charge-loss performance on memory cells, and defect screens (e.g., high-voltage cell stress to screen out weak oxides). We also periodically modify test programs based on continuous learning to improve reliability screens. Each test change must receive Quality and Reliability approval.

FACTORY RELIABILITY MONITORS

Intel defines reliability standards for each product and uses monitors in various stages of product development and qualification to ensure that reliability requirements are met. Some of these monitors are retained during the manufacturing life of a product and can be performed at various stages of manufacturing.

Table 4-1 shows typical reliability stresses and their respective purposes and conditions. Whenever applicable, we select stresses and adapt them to match the fab, package technology and device application.

Table 4-1. Reliability Stresses

Stress	Purpose of Test	Typical Test Parameters
Extended Life Test (ELT)	Determine device and process durability to electrical and thermal stresses for long periods of time.	125°C at maximum Vcc up to 1000 hours –Continuous bias applied
Steam	Test moisture resistance and integrity of plastic packages.	121°C at 15 psi for 168 hrs
Temperature Humidity (85/85)	Evaluate moisture resistance of die in plastic packages under high temperature and high humidity.	85°C at 85% RH for 1000 hours –Continuous bias applied
Temperature Cycling	Detect mechanical reliability problems and thin-film leakage caused by temperature change.	Condition B: –55°C to 125°C air to air, up to 1000 cycles Condition C: –65°C to 150°C air to air per MIL-STD-883C, Method 1011u, up to 1000 cycles
High Temperature Reverse Bias (HTRB)	Evaluate DC program or DC erase-type failure mechanism, charge pulled onto the floating gate from the substrate, or charge pulled off the floating gate to the select gate.	125°C at 7.5 to 8.5V (array stress) for 168 hours
Bake	Assess electron charge retention in the floating gate of an EPROM cell and thermally activated process-related failure mechanisms.	Plastic: 140°C for 1000 hrs Ceramic: 250°C for 500 hrs
Highly Accelerated Temperature and Humidity Stress Test (HAST)	Evaluate the reliability of plastic packages under high temperature and humidity conditions. The conditions used are more severe compared to 85/85. This stress may be substituted for the 85/85 test.	156?C at 85% RH up to 100 hrs 130?C at 85% RH up to 100 hrs –Continuous bias applied

SAMPLE PLANS

Periodic sampling is performed to ensure that each fab or assembly process is monitored. We base the criteria for selection of a sample size on a variety of fabrication or assembly attributes, such as high sensitivity to reliability stress, cavity type, frame type, lead count and die attach method. We also consider such factors as consistent production volume and ease of failure analysis. A three-level plan can be used:

?? **Type I** is reserved for process and assembly families that exhibit a high degree of stability and consistently meet process reliability targets. Very few failures are expected in this plan, and response to failures is quick.

?? **Type II** is used with processes that meet all reliability goals but show a relatively higher defect level than Type I processes. These processes are operating closer to the reliability

targets and require increased sampling sensitivity. A very low level of failures is generated by this plan. Reaction limits and response plans are defined to quickly identify valid process excursions.

?? **Type III** is used for production-qualified products and processes that may require additional stress data to provide a reliability baseline with a good degree of confidence. It is a short-term plan designed to assist in the evaluation of process control capability and stability studies. Higher sample sizes or increased frequencies are used. A certain level of failures is expected in order to measure the defect rate being studied.

We define control limits and reaction plans for each sampling level. The reaction plans are designed to quickly validate any failure, identify its scope and effect on product field reliability, and determine and fix its root cause. Quality and Reliability engineering teams routinely review these indicators and drive appropriate actions and responses to ensure that they are healthy.

MATERIAL SUPPLIER QUALITY

All materials used in Intel manufacturing are under incoming materials control. The Corporate Materials organization manages the quality of wafer fabrication materials (e.g., silicon, chemicals and quartzware) and assembly materials (e.g., packages and molding compound). This organization's responsibilities include:

?? Materials and supplier quality improvement.
?? Materials technology development and engineering.
?? Materials purchasing.

By integrating these activities into Intel commodity teams, we ensure that materials meet ever more stringent requirements at the lowest total cost.

The quality improvement methodology that we apply to meet current and future materials requirements is embodied in our Supplier Continuous Quality Improvement (SCQI) program, which encompasses the following:

?? **Planning and preparation.** Set expectations. Analyze the current situation. Develop an improvement plan.

?? **Supplier qualification.** Align the supplier with Intel expectations. Collect and analyze supplier process data. Bring the supplier into conformance with Intel's expectations.

?? **Supplier-managed improvement.** This includes a supplier self-assessment, an Intel validation of this assessment, a joint Intel/supplier improvement plan and a periodic review.

The materials process flow, illustrated in Figure 4-6, encompasses the following:

?? We initially define materials requirements (e.g., dimensional, functional, visual, reliability-oriented) by technology and manufacturing needs.

?? During development, we characterize and engineer materials to meet or exceed our requirements.

?? After development, we qualify materials for revenue production and transfer them to an Intel volume manufacturing facility, where the processes are exact duplicates of those in the development facilities.

?? After qualification/transfer, we ramp production volume. Materials suppliers with robust and effective quality systems are certified with Dock-to-Stock (DTS) status. DTS suppliers are capable of driving continuous quality improvement on their own, with Intel providing guidance and validation from a customer perspective.

?? From the development through sustaining stages, materials and suppliers undergo continuous improvement using the SCQI process to ensure that they meet our materials quality vision, i.e., that 100% of supplier output for Intel works as expected in our manufacturing processes at the lowest total cost.

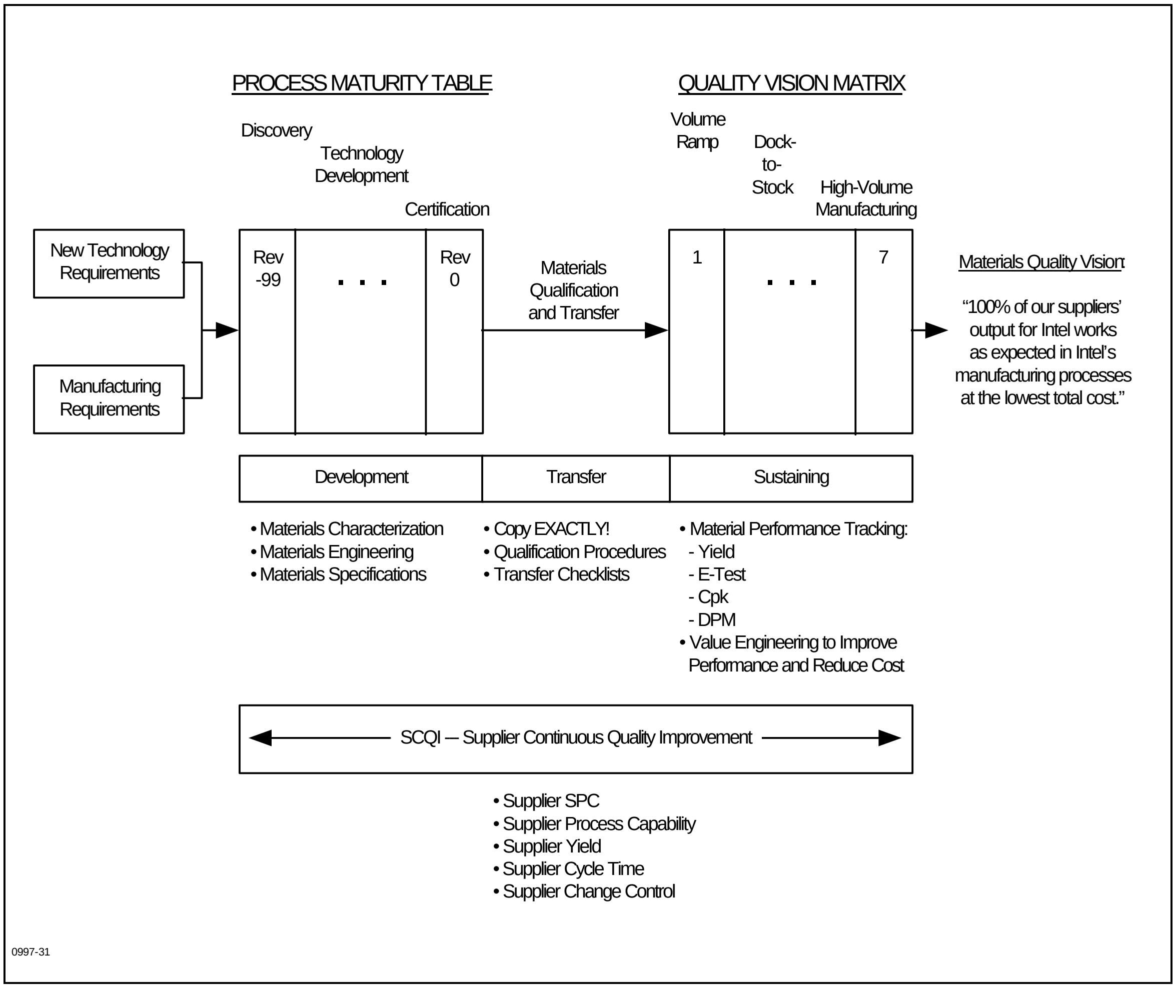

Figure 4-6. Materials Process Flow

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We monitor materials from non-DTS suppliers by incoming sampling inspection, which is performed by Intel Materials Quality Control organizations. For DTS suppliers, we review supplier-collected data on Certificates of Conformance (CofCs). These certificates are supplier documents containing data, statistical analysis and other information. They substantiate the shipment's conformance to all Intel specifications and are sent with materials shipments or electronically.

The possibility of discrepant materials always exists. In the event of discrepant material, we issue a Supplier Corrective Action Request (SCAR) to the supplier and hold a Material Review Board (MRB) to determine whether reliability or manufacturing risks will result from using this material. We then track supplier corrective actions to ensure that root causes are addressed and permanent corrective actions are taken to prevent recurrence.

We also conduct audits of supplier manufacturing facilities on a regular basis. These audits use the SEMATECH SSQA (Standard Supplier Quality Assessment) criteria, which are based on the ISO 9000 quality systems model. We recognize suppliers with exceptional quality systems and material quality performance by granting Preferred Quality Supplier (PQS) status. Only our best suppliers receive the SCQI Award, which honors world-class performance.

SUBCONTRACTOR QUALITY

Intel uses subcontractors to perform some or all of the manufacturing process, including wafer production, assembly, test, and board and system manufacturing. In selecting subcontractors, we evaluate the potential suppliers' ability to meet both technical and business requirements. Only suppliers that measure up to our high standards are qualified to manufacture products bearing the Intel logo.

The quality operating systems (QOSs) of each supplier, while not identical to those at Intel, must deliver the same high level of results that our customers expect. We perform pre-production assessments at subcontractor facilities covering a wide range of QOSs, such as functional analysis/correlation requests, discrepant material disposition, change control and statistical process control. We develop corrective action plans for any QOS judged to be inadequate to meet Intel's and our customers' needs.

Process certifications and product qualifications are performed to the same specifications used for our internal factories and products. In many cases, this means that our subcontractors must collect data from a wider range of stresses and larger sample sizes than their own specifications require. When necessary, Intel will augment the certification or qualification stresses internally.

During the production phase, we review quality and reliability monitors with subcontractors on a regular basis. Additionally, our Corporate Quality Assessment organization performs assessments at predetermined intervals. This data, along with performance to other QOSs, is reported to our key subcontractors as a Quality Scorecard on a monthly or quarterly basis. We also work with our subcontractors to develop continuous improvement plans based on aggressive improvement goals.

As a result of this program, we've been able to offer customers a wider choice of products and increase the availability of some products. In short, we've improved our overall customer support while maintaining high standards of product performance and quality.

CONTROL OF INSPECTION, MEASURING AND TEST EQUIPMENT

Introduction

The primary function of lntel's calibration program is to ensure the measurement capability of any instrument that provides quantitative or qualitative data on Intel products. The program includes mechanical, electrical, electronic and physical measurements. Its purpose is to meet ISO 9002 and customer requirements, which are defined within Intel's Measuring Equipment and Calibration Policy. Accuracy of measurements is ensured by maintaining traceability to national standards.

A network of primary and secondary laboratories located at all major Intel sites around the world provides the calibration service to maintain cost-effective, accurate measurements. Quality Assurance ensures that all inspection and test equipment used in the manufacturing and acceptance of product is under calibration control at all times.

This network maintains or has access to primary and secondary standards for measuring voltage, current, resistance, frequency, mass, light intensity and dimensional parameters. Each site tracks equipment to ensure calibration, schedules calibration and maintains equipment calibration traceability. Each equipment owner has the responsibility of ensuring that his or her equipment is calibrated. Each department is responsible for conformance to calibration policy.
Proper use of the calibration service ensures that all measuring and test equipment meets the specified tolerances. We compensate for and correct any drift, inaccuracies and out-of-tolerances found in equipment. Written notification is required if a significant out-of-tolerance condition is found. Reports of calibration results are available at the certifying facility.

Calibration Traceability

A traceability process links all inspection and test instruments through Intel standards laboratories to the National Institute of Standards and Technology (NIST), acceptable international standards or natural physical constants (see Figure 4-7).
Where no recognized national standard is available, we use consensus standards. These can include an artifact or process used as a de facto standard by agreement of the contractor.

Calibration Capability

Intel tailors measurement requirements for calibration facilities to meet the specifications of each site. Because there are many different testing requirements, each calibration facility has a range of secondary standards designed to the equipment owner's needs. To maintain cost-effectiveness, some calibrations are done off-site at another Intel location or vendor calibration laboratory.

Calibration Intervals

Intel establishes initial calibration intervals for measuring equipment and measurement standards based on manufacturer recommendations or generic class. After we obtain sufficient history of the stability, purpose and degree of usage, calibration intervals can be extended based on risk analysis or shortened to ensure equipment reliability. Thus, we can identify high- or low-reliability measuring and testing equipment and compensate when necessary. A calibration scheduling system enables us to schedule and control the mandatory recall of measuring equipment and measurement standards within established time or calibration intervals.

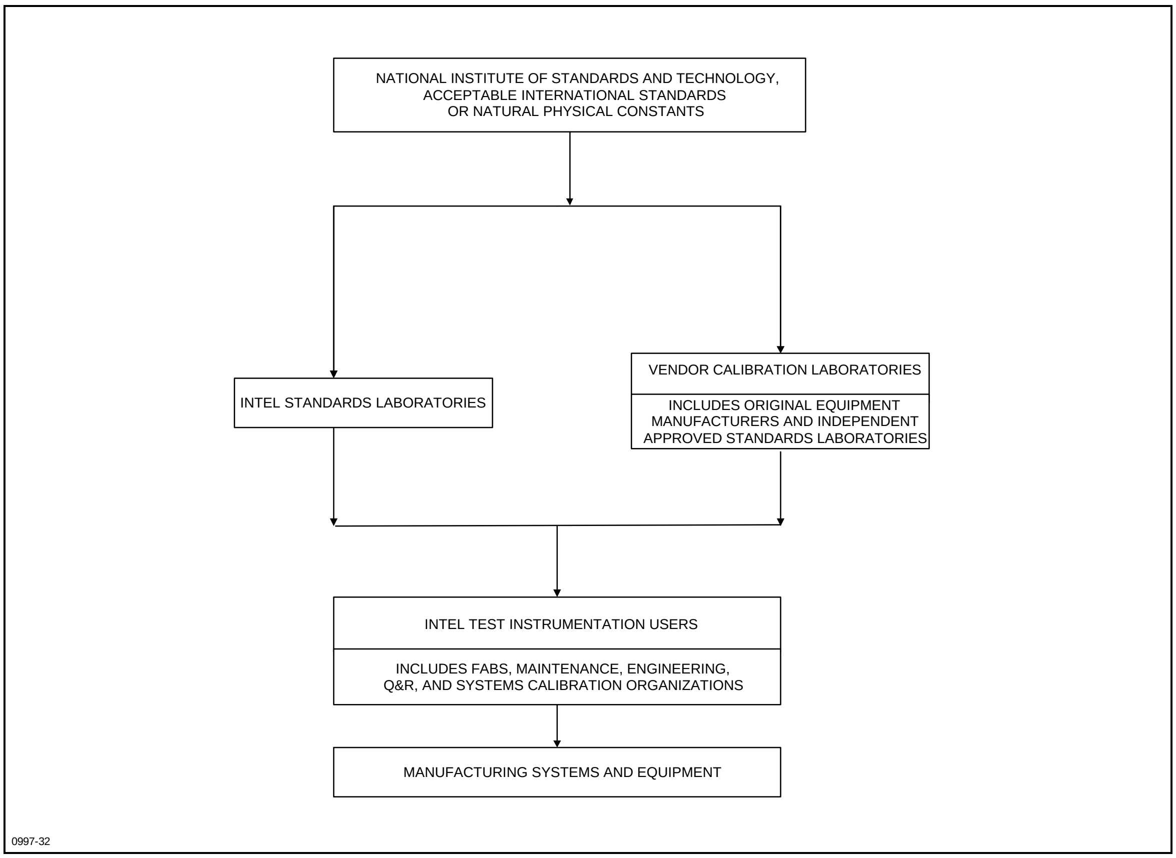

Figure 4-7. Calibration Traceability Chain

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Calibration Records

Intel's system of calibration requires that the following data and equipment information be maintained:

?? Unique identification of units tested.
?? Environmental condition under which the unit is tested.
?? Deviations, correction factors or limits of calibration, if applicable.
?? Equipment owner/user department.
?? Calibration interval.
?? Last calibration date and next due date.
?? Calibration procedures.
?? History of calibrations and repairs performed.
?? Identity of person performing the calibration.
?? Standards used to perform the calibration.
?? Retention of calibration data sheets for a minimum of three years.

Calibration Labeling

Labeling serves several functions in Intel's calibration system. It identifies unique tracking systems, present calibration status and the individual support group. It also serves as a visible indicator of unit serviceability. Some labels are valid only when sealed by a qualified calibration technician or supervisor with the appropriate site calibration stamp.

Calibration Standards

Uniform application of the calibration system at all Intel sites is a necessary part of our support effort. A rigid system of standards and procedures helps ensure product uniformity across our manufacturing sites. In a corporate wide effort, we develop calibration policies and practices for use throughout our locations. We then monitor compliance to requirements using internal audits.

CONTROL OF NONCONFORMING PRODUCT

A corporate specification governs the review and disposition of questionable or discrepant nonconforming product at all Intel sites (fabs, assembly and test, distribution centers and divisions). This specification details the minimum requirements for review and disposition of nonconforming product or raw materials when disposition procedures are not defined in the operation specification. All nonconforming product is subject to a formal risk assessment of potential performance degradation by a Disposition Review Board (DRB), Material Review Board (MRB) or Quality Action Notice (QAN). The purpose of these review boards is to prevent or eliminate the impact of all nonconforming product on Intel’s customers.

The DRB is a local review board whose membership includes Quality and Reliability, Process/Product Engineering and the problem owner. MRB/QAN membership varies by site, product or problem situation, but typically includes Manufacturing, Engineering, Quality and Reliability, Planning and the division quality and reliability engineer or product engineer, if necessary.

The MRB/QAN process begins by identifying discrepant material in a factory. An MRB/QAN meeting is convened to ensure that appropriate actions are taken to:

?? Contain all affected material.
?? Conduct a risk assessment to develop a material evaluation plan.
?? Identify the root cause.
?? Develop a corrective/preventive action.
?? Implement the corrective/preventive action plan.
?? Disposition the affected material.

The MRB/QAN tracks these actions to a successful conclusion and an appropriate material disposition after reviewing the required testing or screening data. The review board creates a final report to document all actions taken to disposition the affected material. The board ensures that all preventive actions (permanent fix for root cause) are completed or transferred to an organization/owner and monitored on a regular basis. These reports form a permanent reference for future excursion management and problem resolution.

The MRB/QAN reports and results help define and drive continuous improvements in several ways. They are followed up in factory self-audits, corporate audits and ISO 9002 audits (if a site is ISO 9002 registered). They are also reviewed regularly for trends that point to fundamental improvements required, and these trends are factored into Intel’s continuous quality improvement plans.

CORRECTIVE AND PREVENTIVE ACTION

Intel tracks corrective and preventive actions in many systems across Intel, such as customer functional analysis/correlation requests, audit findings and the DRB/MRB/QAN system. By completing corrective actions, we ensure that the identified nonconforming product will not impact our end customers. After we identify the root cause for a given problem, we assign preventive actions to avoid a recurrence of the problem.

HANDLING, STORAGE, PACKAGING AND DELIVERY

Introduction

Intel takes special precautions to ensure that all products are handled, stored and packaged in a safe manner. In addition, we ensure that our supply chain aligns with the product delivery needs of our customers.

Handling and Storage

During production, Intel products are handled and stored according to procedures designed to prevent damage to the product. We control physical damage by reducing and eliminating manual handling in favor of controlled, automated handling. We also regularly monitor and control moisture/humidity levels during production to eliminate corrosion and degradation. Moreover, we protect product from electrostatic discharge (ESD) through a number of controls, including the grounding of manufacturing personnel and equipment and the use of static-dissipative garments.

Packaging

When processing is completed, we pack and ship finished products in qualified transport media that continue to protect them from physical, moisture and ESD damage. The transport media types used are static dissipative and comply with Intel specifications, which are based on finished product dimensions to reduce physical damage during shipment. Products that are extremely sensitive to humidity are protected by a hermetically sealed, static-dissipative bag before placement into the final shipping box.

Delivery

Intel recognizes that product distribution is a complex process. That’s why we’ve created an organization that integrates the product distribution logistics operation with planning groups which manage customer interaction, factory supply and product scheduling. The common goal of this organization is to align our supply chain with our customers’ product delivery needs. Our Vendor of Choice ratings and delivery performance are two of the organization’s major success indicators.

The systems and processes of our factories and distribution centers are linked and have a common management structure. Customer service groups in each distribution center ensure that customer requirements are supported through the product distribution network. Integrated, interconnected systems transfer customer order data to Intel’s factory and distribution network to ensure information accuracy. These systems allow our supply chain network speedy access to customer order data for quick response to requirements and changes. Self-checking systems and automated processes help to ensure the accuracy of product delivery to customers. We’ve also connected our systems with our carrier transport partners for accurate data transfer. The interconnected data network allows us to minimize errors and respond expeditiously to customer inquiries regarding order status.

Intel’s distribution centers, which are ISO 9002 certified, are committed to aggressive, ongoing improvement. A highly effective customer feedback process is key to improvement in our product distribution network. This process includes data collected as part of our Vendor of Choice program as well as specific customer-reported errors, which are collated in our Customer Trouble Report (CTR) system. The distribution centers have quality teams at the operator level that review the data and then define and implement corrective actions to eliminate errors. Managers of the distribution centers, Quality and Reliability, and Logistics groups regularly review CTR data, containment plans and corrective action progress. The CTR system also has a sub-process to provide quality feedback to Intel’s upstream factories and subcontractors about errors detected in Intel’s internal processing. We monitor the performance of our business partners, including factories and carriers, on a regular basis to identify, contain and correct process problems.

The mission statement of Intel’s Logistics group summarizes its customer service vision as follows: “Provide customers with outstanding and cost-effective distribution services: Right product, right place, right time, every time.”

PRODUCT IDENTIFICATION AND TRACEABILITY

Introduction

Intel's traceability system enables full product identification and tracking through all stages of manufacturing, storage and shipment to the first point of sale. Identification methods include lot tracking numbers that allow forward and reverse traceability of products. To enable effective utilization of equipment in component production, we've established batching guidelines. Record retention guidelines are in place to ensure that lot history is maintained.

Product Identification

Intel moves production material through the factories in lots. For component products, we assign a unique fab lot number consisting of eight alphanumeric characters to a lot as it moves through fabrication and sort operations. When the lot is released to assembly, we add two more digits to the lot number to form the Assembly Lot Traveler/Assembly Process Order (ALT/APO) number, which is used throughout the assembly operation. When the lot is released for testing, we give it an entirely new eight-digit alphanumeric number called a Test Process Order (TPO) to move through the test process. Finally, we assign a unique Finish Process Order (FPO) number to the lot as it moves through the final test, mark and pack operations. The FPO number is marked on the top of every component except the tape carrier package (TCP); it is also marked on the bar-coded label of each box. The ALT/APO is usually marked on the bottom side where space permits. The FPO number indicates the date code of the lot to control age of shipments and is the key identifier linking the lot to its manufacturing history and shipment destination records.

Board and system production materials are moved through the factories in work order lots. In these work orders, we assign a unique serial number to individual boards or systems as they move through the manufacturing operations. This serial number is the key identifier to link the board or system to its manufacturing history and shipment destination records.

Batching

For practical reasons in component production, we optimize lot size for equipment utilization, and batching is inevitable. However, all finished products must be traceable back to their assembly lot numbers. Die from different fabs and steppings may not be combined in any ALT/APO through assembly. After test, we batch FPOs under guidelines that may allow smaller lots to be combined to form a desired lot size without jeopardizing traceability. Our board and system assembly uses a continuous flow method instead of batching. Each board or system is traceable to the released work order through the unique board or system serial number.

Records Retention/Retrieval

The primary record for component product traceability is the FPO. All the component product lot history, including ALT/APO and parent TPO/FPO, is recorded in this document. The FPO documentation accompanies all shipments from test to the distribution center, which also maintains sales orders and shipping records. For board and system manufacturing, the unique serial number provides this traceability. Records pertaining to product traceability must be kept for up to seven years or a period specified in Intel's Records Management Policy.

During the investigation and control of a process excursion, timely access to critical traceability information is absolutely required. Currently in components manufacturing, the Integrated Lot Traceability System (ILTS) can provide lot genealogy, last known location and status of products. This system facilitates the tracing of material from the customer back to the fab lot and from the fab lot to the customer/location. ILTS gets its data from the Global Inventory Management System (GIMS) database, which contains lot-level detail of all Intel's work in progress and inventory from wafer start through customer delivery. Typical users of ILTS include Quality and Reliability, Planning, Manufacturing, Logistics and management personnel. Figure 4-8 shows how data is fed into GIMS and forwarded to ILTS.

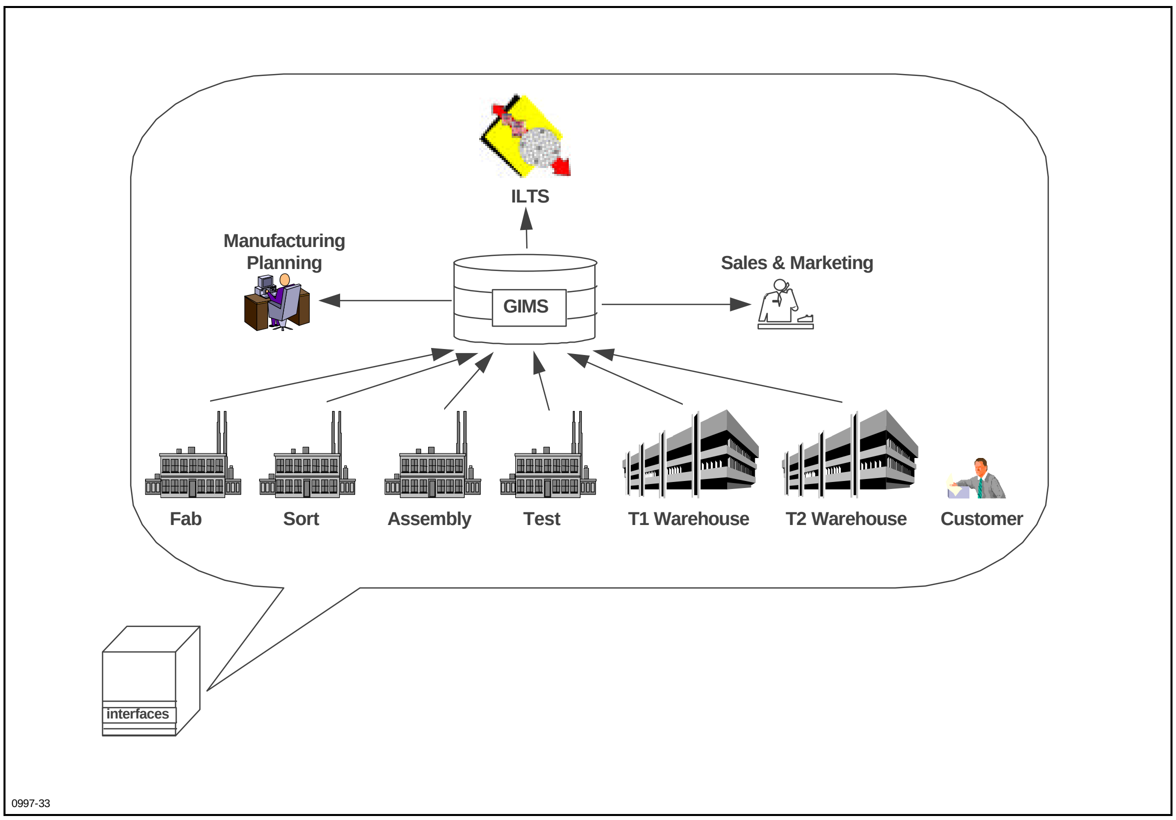

Figure 4-8. Global Inventory Management System

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Traceability Responsibilities

Each manufacturing site and distribution location establishes and enhances its internal systems to support Intel's traceability policy. Quality and Reliability personnel in each site are responsible for verifying that traceability requirements are met. Periodically, the Corporate Quality Assessment organization performs audits to ensure conformance to policy. Similarly, Intel's subcontracting groups ensure that all subcontractors building Intel products comply with the traceability policy.

CONTROL OF QUALITY RECORDS

Intel maintains quality records that demonstrate the effectiveness of our quality system and achievement of required quality system standards. Quality records are critical tools for analyzing results and trends. They not only enable us to determine the need for corrective action, but also help us track ongoing improvements.

We have established procedures for identifying, collecting, indexing, filing, storing, maintaining and disposing of quality records. All quality records for a given produc?¾whether centrally located or retained by individual organization?¾are identifiable, retrievable and legible. Intel's Corporate Records Management has procedures for submitting records to off-site storage and for retrieving them. These procedures also state minimum record retention periods. Quality records in electronic format are available on-line and are subject to regular back-up according to documented procedures.

INTERNAL QUALITY AUDITS

Introduction

Intel's quality assessment methodology, which is executed at the corporate and site/self-audit levels, links assessment activities to business planning processes. This methodology provides a global focus that balances product performance with quality system performance, and external requirements with internal business needs. ISO 9000 provides the baseline criteria for internal assessments at the corporate and site/self-audit area levels (see Table 4-2 for quality assessment criteria). Our assessment process ensures continued satisfaction of customer requirements and demonstrates that (1) our baseline performance is valid, (2) we're using common practices, and (3) real improvements are being made through increased accountability at the source.

Responsibility for the development, implementation, training and continuous improvement of Intel's quality assessment methodology lies with the Corporate Quality Assessment (CQA) organization. Corporate assessors administer the overall methodology through a network of plant auditors and coordinators, who are responsible for managing their site's or organization's self-audit program.

Table 4-2. Quality Assessment Criteria

ISO 9000 STANDARD ELEMENTS	
Management Responsibility	Control of Inspection, Measuring and Test Equipment
Quality System	Control of Nonconforming Product
Contract Review	Corrective and Preventive Action
Document and Data Control	Handling, Storage, Packaging and Delivery
Purchasing	Control of Quality Records
Product Identification and Traceability	Internal Quality Audits
Process Control	Training
Inspection and Testing	Statistical Techniques

Corporate Quality Assessments

CQA auditors perform corporate quality assessments of Intel manufacturing sites/operations. The auditors have varying levels of quality system expertise and process knowledge, but at a minimum they've been trained in basic auditing methods and techniques, business process auditing and ISO 9000, as applicable. Their training may also include American Society of Quality Control (ASQC) certification.

All CQA assessments include the following elements: planning and preparation, performance, findings definition, tracking of corrective action closure and effectiveness, and continuous improvement planning. The CQA auditor and his or her business partner customize the scope for each assessment cycle. They use information gathered and analyzed from the following sources: compliance and customer requirements, corporate issues and opportunities, business results/process needs and an audit maturity matrix (see Table 4-3). The matrix focuses on the maturity of the site/operation self-audit program to drive continuous improvement of quality systems and processes.

Table 4-3. Audit Maturity Matrix

MATURITY MATRIX LEVEL	SCOPE AND FREQUENCY
Level 1	Limited Scope: Three Days, Every Two Years
Level 2	Limited Scope: Three to Four Days, Every Year
Level 3	All Areas: Four Days, Every Year
Level 4	All Areas: Four to Five Days, Every Year

To ensure continuous improvement of the quality assessment process from cycle to cycle, the audit function manager and the CQA auditor collect formal feedback from assessment participants and incorporate the necessary changes into the next assessment cycle.

Self-Audits

At a minimum, sites/operations perform annual self-audits of their quality system and processes. Self-audit teams comprising functional content experts are trained on basic auditing methods and techniques as well as ISO 9000.

All self-audits include the following elements: planning and preparation, performance, findings definition, tracking of corrective action closure and effectiveness, and continuous improvement planning. These audits are more in-depth than CQA assessments and allow the reporting of results without fear of management punitive action. Regularly scheduled management reviews monitor corrective action closure and the overall effectiveness of the program.

STATISTICAL TECHNIQUES

At Intel, we utilize statistical process control (SPC) as one component of our total quality program. SPC tools and techniques are applied to design and manufacture quality, reliability and customer satisfaction into our products and services.

We emphasize training in statistics, SPC, structured problem solving and team building. Site statisticians are available to assist employees in using statistical methods such as design of experiments and production data analysis. SPC is an essential part of our ongoing effort to drive defects per million (DPM) levels to zero.

Intel's continuous improvement efforts are based on a structured problem-solving methodology that has been taught to the majority of employees. This methodology allows cross-functional teams to form quickly and address problems with a common approach and language. Statistical tools are an important part of these continuous improvement efforts. Methods for improvement and process optimization vary from simple graphs to sophisticated statistical techniques. Pareto analysis and, if needed, statistical experimental design are used to pinpoint the root cause of a process variation or problem. Examples of commonly used techniques include trend charts, process flow charts, scatter diagrams and response surface analysis.

DOCUMENT CONTROL

Introduction

Intel has an extensive system for document control and engineering change control. The Document Control Management System incorporates external and internal customer requirements for quality assurance, assessment and improvement into our operations. This system encompasses specifications that represent the cumulative technical know-how of design, development and manufacturing activities.

Document Control Centers (DCs) are located at all Intel facilities to support geographically dispersed organizations. Corporate Document Control (CDC) provides guidelines for the approximately 56 satellite DCs on minimum requirements for controlling and handling Intel documents. Each local DC augments these with requirements specific to its respective organizational and customer needs. CDC acts as a centralized focal point for developing, implementing, standardizing and controlling Intel specifications worldwide.

Document Structure

Intel's document structure is shown in Figure 4-9. Moving from the top of this structure downward, we see that documents become more specific in their purpose and scope. In addition, document content becomes increasingly detailed. Corporate business principles state Intel's leadership position and are applicable to all Intel employees. Group guidelines and governing specs state high-level requirements and methods to achieve synergy across operations; they apply to several operations in a business group. Operational policies and procedures are for a specific operation or function within a business group.

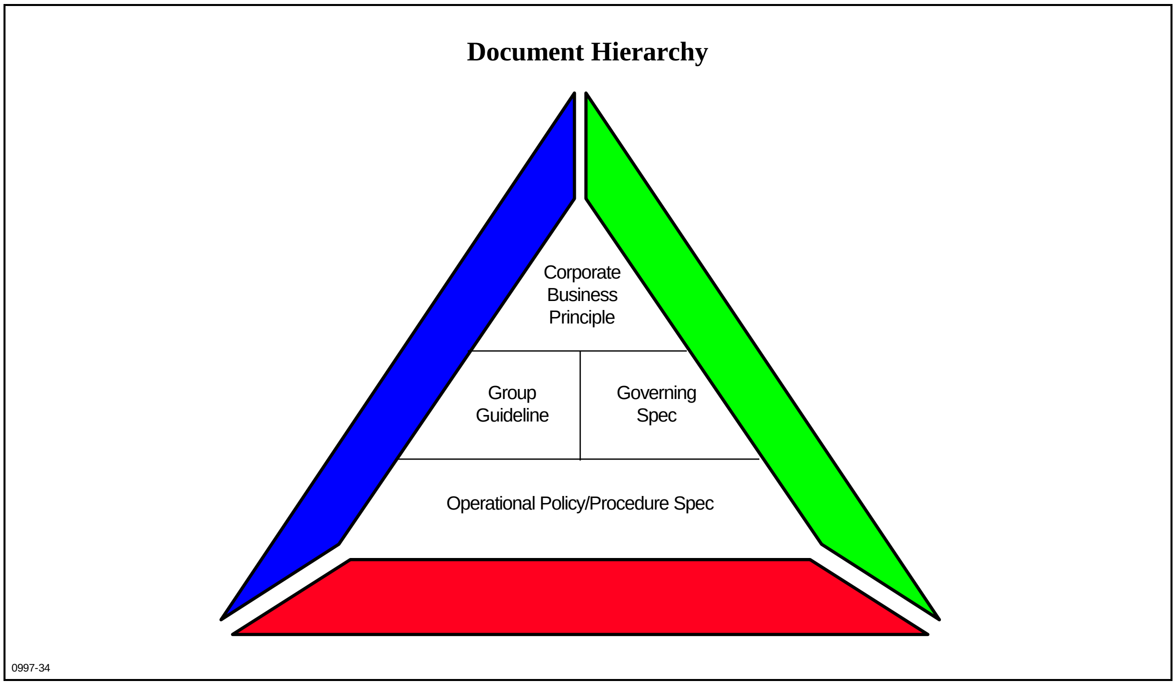

Figure 4-9 Document Hierarchy

Corporate Quality's deployment methodology defines the process steps for ensuring that a policy, procedure, methodology or requirement is followed and used appropriately. All new Corporate Quality policies, methodologies, procedures and requirements, as specified in group guidelines, governing specifications, and operational policies and procedures, use this methodology.

Methodology for Controlling Information

Document Control manages each document/specification through its life cycle and is responsible for all document transactions within the following key business processes:

?? **Document creation** is the process of meeting a business need by creating documents/ specifications that will provide users with required information.

?? **Document approval** is the process of gaining collective agreement on the content of Intel's controlled information. It also involves the regulation of controlled documents to ensure that proper approvals have been received for specification revisions, creations or obsolescence.

?? **Document distribution** is the transfer of the right information to the appropriate user(s) in a timely manner. This includes the transfer and preservation of a document in a secure location with controlled access.

?? **Document retrieval** is the process by which documents are located, recovered and appropriately dispositioned. This includes retrieving the document from a current or archived directory or file.

TRAINING

Intel believes that high-performing teams and individuals are essential for an integrated, successful quality system. In order to develop the skills, knowledge and culture necessary for exemplary performance, we emphasize a broad range of training and development expectations for both individuals and teams.

For example, we provide a core set of classes that all employees must complete as part of an orientation program. These core classes cover a range of skills and knowledge that are central to Intel's values and performance-oriented culture. The orientation program focuses on our culture and values, general improvement strategies and effective teamwork. During orientation sessions, seasoned members of our workforce share their real-life experience with new employees.

For all employees, the orientation program is supplemented with specific training and development activities. Each employee and his or her manager define these activities as part of an ongoing personal development plan. Plan activities are geared toward developing specific technical skills required for the job and the skills needed to succeed in Intel's culture and team-focused environment.

Three main strategies provide the tools, skills and culture necessary for developing and maintaining high-performing teams and individuals:

?? **Intel's Business Practices Network (BPN).** BPN is responsible for development of general leadership and management skills. Its scope includes the development of strategic planning processes that promote quality management and teamwork, and the deployment of basic quality tools such as problem solving and statistical process control. Moreover, BPN strives to embed the skills necessary for reducing time-to-productivity within factories and other groups. BPN is also responsible for deploying a self-assessment methodology that allows Intel groups to analyze processes and systems to identify their strengths and areas for improvement.

?? **Intel University.** Intel University is responsible for deployment of Intel's general curriculum. The Intel University system maintains a base of trained instructors, monitors the quality of courses delivered and provides administration and tracking services. Employees can select from a variety of classes that provide technical skills such as design methodologies, application of quality and reliability tools, and design of experiments. Intel University also provides classes that address effective teamwork and personal growth, such as constructive communication and effective listening.

?? **Targeted training to support the tactical goals of Intel's functional organizations.** Factories, groups and divisions also have an internal training function that manages their training and development needs. For example, each Intel factory has a training group that is responsible for developing manufacturing skills specific to its needs. All manufacturing technicians and production operators receive training for their job and are certified to a set of competencies.

Another such training function is our Components Training organization, which is responsible for developing the general skills necessary for manufacturing excellence in Intel's wafer fab and assembly/test facilities. Training curriculums and activities are provided for various manufacturing job functions, including line supervisors, engineers and factory support personnel.

In addition to these examples, groups and divisions often manage their own specific training needs, using existing Intel resources as well as those developed within their organizations.

The overall goal of Intel's focus on training and development is to create a high-performing culture that is based on individual skills as well as quality-oriented teamwork. We believe that this culture contributes to a foundation of total quality management that ultimately results in customer satisfaction.

CONCLUSION

The Quality and Reliability group's involvement with Intel's manufacturing processes is a proactive one that spans the entire fab and assembly process. Our factories use ISO 9000 as their baseline quality system to continuously boost product quality and reliability.

By applying lessons learned from past experience and implementing new breakthrough methods, we continue to seek improvements in our current processes and products. Moreover, by striving to make our current technology robust in quality, we can successfully focus on meeting future challenges posed by rapidly increasing process and product complexity.

Everyone involved in Intel's world-class manufacturing quality system makes continuous improvement a way of life. Exceeding our customers' expectations is our ultimate goal.

Glossary

GLOSSARY

ALT: Assembly Lot Traveler
APF: Assembly Package Family
APO: Assembly Process Order
ASQC: American Society for Quality Control
ATD: Assembly Technology Development
Bonding: The act of connecting package leads to specified locations on the chip via wire.
CCB: Change Control Board
CDC: Component Document Control
Chip: One square on a wafer containing a single integrated circuit. The substrate on which all active and passive components of a circuit are fabricated; also called a die.
CITR: Confidential Information Transmittal Record
Class Test: Measurement of assembled device performance. Products are categorized by speed/power/performance criteria; also called final test.
Cleanroom: This area features a controlled environment with filtered air that eliminates essentially all of the dust and dirt.
CNDA: Corporate Non-disclosure Agreement
CofC: Certificate of Conformance
Control Limit: A statistically defined limit that determines whether or not a process has changed significantly as compared to past history.
CPU: Central Processing Unit
CQ&R: Corporate Quality and Reliability
CQA: Corporate Quality Assessment
CQE: Customer Quality Engineer
CQN: Corporate Quality Network
CTR: Customer Trouble Report
DC: Document Control
DCCB: Divisional Change Control Board
DFE: Design for Environment
DFM: Design for Manufacturability
DFQR: Design for Quality and Reliability
Die: A single integrated circuit separated from the wafer on which it was made; also called a chip.
DPM: Defects Per Million
DRC: Design Rule Checker
DTS: Dock-to-Stock
EB: Employee Bonus
EOLM: End-of-Line Monitor
ESD: Electrostatic Discharge
FA: Failure Analysis
FA/CR: Functional Analysis/Correlation Request
FAE: Field Application Engineer
FIT: Failure in Time
FPF: Fabrication Process Family
FPO: Finish Process Order
FSE: Field Sales Engineer
GCCB: Geographical Change Control Board
GIMS: Global Inventory Management System
GRs: General Reviews
GSS: General Semiconductor Specification
ICD: Intel Commit Date

ILD: Interlayer Dielectric
ILTS: Integrated Lot Traceability System
Lead: The connection to an element on the integrated circuit.
MBP: Management by Planning
MRB/DRB: Material Review Board/Disposition Review Board
MTS: Module Target Spec
NIST: National Institute of Standards and Technology
Package: The container used to hold an active semiconductor device.
PAI: Planning at Intel
PCCB: Process Change Control Board
PCN: Product Change Notice
PDC: Passive Data Collection
PDQE: Product Development Quality Engineer
PDT: Product Development Team
PM: Preventative Maintenance
PQE: Product Quality Engineer
PQRE: Product Quality and Reliability Engineer
PQS: Preferred Quality Supplier
Presort: Sort type electrical test in fabrication.
Q&R: Quality and Reliability
QAN: Quality Action Notice
QFD: Quality Function Deployment
QIP: Quality Improvement Process
QSC: Quality Support Center
SCAR: Supplier Corrective Action Request
SCQI: Supplier Continuous Quality Improvement
Silicon: Metallic element that forms the substrate in most semiconductor devices.
SLRP: Strategic Long-Range Planning
Sort: Same as Sort Test
Sort Test: First electrical test of actual devices at the wafer level.
SPC: Statistical Process Control
Spec Limit: Absolute acceptable limit for a process parameter.
SRs: Spec Reviews
S-Spec: Specifications Intel uses to customize products to unique customer requirements.
TD: Technology Development
TPO: Test Process Order
TTS: Technical Target Spec
VOC: Vendor of Choice
Wafer: A thin piece of silicon sliced from a cylinder-shaped crystal.
Wafer Sort: Same as Sort test.

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